Innovative Design Interventions to Address Safety-related Issues in FMCG Industrial Shopfloor: Ergonomics Perspective

A Thesis submitted in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

in Design

by

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DECLARATION

I, **Mr. Gurdeep Singh (Roll No. 176105105)**, a bonafide student of the Department of Design, Indian Institute of Technology (IIT) Guwahati, hereby declare that the work contained in this thesis titled ***'Innovative Design Interventions to Address Safety-related Issues in FMCG Industrial Shopfloor: Ergonomics Perspective'*** is carried out by me during my enrolment period as a student (January 2018 – March 2024) under the supervision of Prof. (Dr.) Sougata Karmakar, Professor, Department of Design, Indian Institute of Technology (IIT) Guwahati, Assam, India. This work carried out for the award of Doctor of Philosophy (Design) is my original contribution done under the supervision of my supervisor. **It has not been submitted elsewhere for the award of any degree or diploma**. The guidelines provided by the institution have been duly followed while preparing this thesis, and I have confirmed the norms and guidelines prescribed in the institute's ethical code of conduct.

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CERTIFICATE

This is to certify that the work contained in this thesis titled ***'Innovative Design Interventions to Address Safety-related Issues in FMCG Industrial Shopfloor: Ergonomics Perspective'*** has been carried out under my guidance and supervision. It is a bonafide research work of my research scholar, **Mr. Gurdeep Singh, Roll No. 176105105**. This work, submitted for the degree of Doctor of Philosophy (Design), is original and contains no materials previously published or written by any other person for the award of any degree or diploma at the Indian Institute of Technolgy (IIT) Guwahati or any other institute or university. All the requirements (including mandatory coursework) as per the rules and regulations prescribed in the Ph.D. ordinance for submitting the thesis for the Ph.D. degree of the Indian Institute of Technology (IIT) Guwahati have been fulfilled by the candidate.

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Dedicated to

My Mother-in-Law

Late Smt. Surinder Kaur

whose profound motivation helped me in commencing this research journey.

Her unparalleled support rendered in this endeavor

was a divine blessing.

My Parents

Smt. Nachhatar Kaur & Shri Paramjit Singh

whose unwavering support and drive throughout my life have inspired me to pursue education and continue evolving as a good human.

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to keep pushing for my life's ambition.

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EXECUTIVE SUMMARY

Background/ Present Scenario

Fast Moving Consumer Goods (FMCG) are low-priced items used with a single or limited number of consumption occasions (Baron et al., 1991). They are sometimes referred to as consumer packaged goods or groceries. Over the past two decades, the FMCG industry has witnessed tremendous growth patterns globally (World Bank, 2023; IBEF, 2024). The FMCG industry makes a significant contribution to the world economy. It has been the most critical contributor to the GDP of every country globally and is also the major employment source within these countries. The FMCG manufacturing units in India are rapidly expanding to Tier II and Tier III Indian cities owing to government support and policies. The northeastern Indian states, especially Assam, have witnessed the rapid establishment of Indian FMCG manufacturing units supported by government subsidy and tax rebate schemes (NEIPP, 2007; NEIDS, 2017; IIP, 2019). As the overall FMCG sector covers a highly diversified range of manufacturing activities, the paucity of literature pertaining to Occupational Safety and Health (OSH) in FMCG poses a severe challenge to the studies to be undertaken by the researchers in this domain. Typically, the major issues that prevail in the food and beverage manufacturing/ processing units comprise slips, trips, and falls due to wet, slippery floors, ergonomic issues, high/ cold temperature exposure, use of sharp cutting tools, especially in meat cutting units, chemical exposure, etc. (Shizue Tomoda, 1993; ILO, 2023; BLS, 2024). OSH issues concerning FMCG manufacturing industries engaged in household/ personal care products (toiletries, detergents, shampoo, hair oil, etc.) and health care products (over-the-counter drugs) remain less explored (Singh and Karmakar, 2021). The following research gaps persist in the context of ergonomics and OSH-related research in the industrial sector.

Research Gaps

- In the Indian scenario, ergonomics and OSH-related research are mainly dedicated to the durable goods manufacturing sector working in the micro, small, and medium sectors, and various context-specific recommendations in the context of shopfloor layouts and minor design interventions for workstation design have been suggested.
- The majority of the research conducted in the field of ergonomics and OSH focuses on investigating the prevalence of several ergonomic stressors and their associated risks; little effort has been given to propose/ offer 'design ergonomic interventions' as potential/ mitigating solutions. Such research remains limited to diagnostic studies, thereby proposing recommendations from the OSH perspective that include available

standard guidelines (preventive measures, physical exercise, therapy, rehabilitation measures, etc.) that may work for improving occupational health.

- So far, the reported industry-related research has mainly been concerned with the standardized work activities and practices of the industrial shopfloor and has drawn maximum attention from the researchers. Context-specific non-standardized work practices have remained least explored on the industrial shopfloors.
- Scanty research has been carried out in the field of FMCG that can also be classified into the fields of production/ operation and management-related aspects; focus on ergonomic and OSH issues in FMCG is almost negligible.
- Research within the Indian FMCG sector is mainly concentrated on management aspects, and there is no reported study on this sector from an ergonomics and OSH perspective. Ergonomic stressors and OSH hazards related to paced assembly, spatial arrangements of workers across paced assembly lines, hazardous risk factors, context-specific non-standardized work activities, and efficacy of work measurement tools have not been studied in the context of the FMCG industry.

Research Questions

The following research questions associated with the research gaps are instrumental in the present research context.

R.Q. 1: What are the current trends of ergonomic-related research and its corresponding ergo tools/ techniques used in diverse Industrial setups?

R.Q. 2: What are the various OSH-related issues prevailing at manual/ semi-automated Indian FMCG manufacturing units?

R.Q. 3: Which area of concern from OSH purview must be prioritized according to the shopfloor workers, manager/ supervisors, and factory management?

R.Q. 4: What are the various criteria or considerations to be taken care of for addressing the identified OSH-related issues in the FMCG shopfloor?

R.Q. 5: What could be the most feasible solution to address identified OSH-related issues in the FMCG shopfloor from the ergonomics perspective?

R.Q. 6: Will the same solution be applicable/ implementable for different scales of production/ production levels in the FMCG production process?

R.Q. 7: How can the implemented solution be tested/ justified?

R.Q. 8: What should be the actionable framework to address OSH-related issues for factory shopfloors with different scales of production?

Problem Statement

A detailed analysis of the available literature reveals the paucity of ergonomics-related research looking into the OSH aspects in an industrial scenario, especially in FMCG sectors. Reported scanty research directed towards OSH mainly deals with issues in shopfloor production processes and assembly-related work of varied industrial setups. Such research generally focuses on considering the standardized work practices of the respective domain. Ergonomic study on FMCG industrial shopfloor is rarely explored and deserves immediate attention, realizing its high potential for generating employment and enhancing GDP across the globe.

An ergo-audit conducted at twenty FMCG manufacturing units revealed the presence of various ergonomic stressors, bottlenecks to productivity, and safety-related issues. As per a unanimous opinion, all the stakeholders (shopfloor workers/ safety in charge/ factory management) considered the non-standardized work activity of reworking defective pouches/ sachets as the critical area of concern. Due to the non-availability of standard tools, the current rework activity involves using sharp cutters/ blades held in bare, slippery hands. It is prone to nicks, cuts, and injuries, posing a safety concern. In addition, it challenges factory management to adhere to basic safety compliance. Besides, the forceful manual hand squeezing of the cut pouch/ sachets to extract in-filled liquid leads to drudgery and contamination. Being a non-standardized work activity, no Original Equipment Manufacturer (OEM) has looked into the concerns of this activity. Although knowing the safety concerns involved in this activity, the stakeholders are compelled to resort to using inadequate tools in varied work conditions. There is a dire need to develop innovative safety-enriched tools/ apparatus as a mitigating solution. Such tool/ apparatus must be capable of eliminating the use of sharp cutter/ blade in bare, slippery hands and eliminate manual hand squeezing. It will help promote safety and well-being in such rework activities.

Aim and Objectives

***Aim**:* The current research aims to address the safety-related issues in the FMCG shopfloor through ergonomic design and the development of innovative tools/ devices constrained by the scale of production, cost, and available resources.

Objectives: In order to fulfill the aim of the current research, the following objectives were set to achieve the goal:

- To understand the state-of-the-art literature on ergonomic issues and the implementation of ergonomic interventions in diverse industrial sectors.
- To study the OSH-related issues in the Indian FMCG shopfloor.
- To identify the most critical areas of concern in the context of work/ worker safety.
- To design and develop innovative context-specific ergonomic design interventions as a mitigating solution.
- To evaluate the efficacy of the developed innovative design interventions.
- To propose a framework for developing safety-related design interventions for the factory shopfloor.

Hypothesis

***Hypothesis 1 (Q1 – Q8)**:* The design and development of innovative tools/ devices in the context of OSH on the shopfloor of the FMCGs is constrained by the scale of production, cost, and available resources.

Methodology

A preliminary ergo-audit as per the IEA, ILO, and OSHA guidelines was conducted at twenty FMCG manufacturing units working under a semi-automated setup and engaging a large number of manual laborers. These manufacturing units were located in the northeastern Indian states, particularly Assam, and primarily manufactured personal care goods, viz. hair oil, shampoo, serum, detergents, etc. The field observations at such FMCG manufacturing units revealed several insights regarding the prevailing OSH scenario. Awkward posture adoption due to anthropometric mismatch, the prevalence of non-standardized work activities leading to accidents, injuries, haphazard implementation of lean manufacturing principles, the prominent use of ill-equipped workstations and resorting to non-standardized tools for carrying out context-specific work activities were common among the shopfloor working of these manufacturing units. Despite the varying scales of production levels, these factors remain prevalent among all shopfloors, and their intensity varies per the production scale.

To steer the research further, the most critical area of concern was chosen in consultation with the stakeholders (shopfloor workers, safety in charge, and factory management). Card sorting sessions, discussions, and interviews were held with the stakeholders to select the most critical area of concern and look for possible interventions that may be proposed to provide mitigating solutions. The non-standardized work activity, i.e., the rework of defective pouches/ sachets, was selected as the most critical area of concern, and innovative design interventions based on ergonomic and design principles were deemed necessary for further research and action. As this activity prevailed at FMCG manufacturing units working under varying production scales, it was assumed that a single solution (an innovative tool/ apparatus) might not be feasible for all such manufacturing units. Three different manufacturing units (factories) working under different production scales were chosen as the representatives of small-scale, medium-scale, and large-scale production units.

The specific needs of each industry were identified, and the three different levels of mitigating solutions (safety-enriched pouch/ sachet cutter) were developed, deploying a systematic product design process based on ergonomic principles. Multiple concepts for the intended design solution were generated using a Morphological chart, and concept screening was done using the Pugh Chart to choose the best feasible concept among those. A virtual mock-up (CAD model) of the selected concept was developed and shown to the stakeholders on laptop screens to explain the operational mechanism and get their feedback. The final iterated CAD model of the intended pouch/ sachet cutter was prepared following their inputs. Various human factor principles were considered while developing the final model of the product. The anthropometric and biomechanical considerations focused on hand anthropometry, wrist's range of motion, overall posture required for using the tool/ apparatus developed, dimension of developed tools according to intended posture, and corresponding workstation, etc., were primarily considered while designing the apparatus. For the development of the tool/ apparatus, the Indian Anthropometric Database (Chakrabarti, 1997) was considered. Several parameters were considered for determining product features using different population sizes/ samples from that database.

Further, the physical prototype of the intended product was developed. Once the apparatus's physical prototype was ready, the field trials were carried out at respective factory shopfloors to understand the product's functionality and related consequences/ insights. The data regarding productivity (number of pouches cut) and other physiological/ anthro-biomechanical parameters were taken to understand the exertion levels of workers while using the developed product. For an assessment of the product's compatibility, the human factor evaluation based on physical exertion level using Heart Rate (HR), fatigue level measurement using handgrip strength, and cognitive load assessment was performed for the existing and improved scenarios. Biomechanical posture compatibility evaluation for the newly developed cutter was assessed by minutely observing the 'Wrist' posture as it was the most prominent body part involved in the entire activity. The newly developed cutter's user acceptance (usability evaluation) was measured by administering the System Usability Scale (SUS) questionnaire.

Following the factory trials, the developed apparatuses were found effective in mitigating safety concerns and various ergonomic stressors associated with FMCG rework at their factory shopfloors. The stakeholders well received the developed products, and these products were capable of eliminating the need to hold the sharp cutter/ blade in bare, slippery hands and forceful manual hand squeezing, and this promoted safety in such tasks.

Results

Three different innovative safety-enriched pouches/ sachet cutters were developed for factories A, B, and C, and those were the representatives of the factories working under small-scale, medium-scale, and large-scale production levels, respectively.

- A hand-held pouch/ sachet cutter capable of cutting 5-10 pouches/ sachets at a time was perfectly suitable for Factory A and its work requirements. It is a low-cost, innovative solution designed and developed for cutting smaller numbers of pouches and sachets and is simple in construction. It can be made in-house using simple construction material (it involves simple mechanisms that can be replicated/ imitated) or directly procured from the market at a cheaper cost.
- Factory B was satisfied with the mid-level hand-held pouch/ sachet cutter, which was hand-held and based on three assemblies: cutting, roller squeezing, and containing assembly. It can cut multiple pouch/ sachet strips at a time and thus rework large numbers of pouches/ sachets, probably 25-100 pouches/ sachets at a time. It is of mid-

level complexity, involves several integrated mechanisms/ assemblies, and requires higher costs to procure.

- A semi-mechanized variant of the pouch/ sachet cutter was found suitable for the needs and requirements of Factory C as it was involved in the reworking of the higher number of pouches/ sachets at a time of the order of 250-500 pouches at a time. Mechanization of this innovative pouch/ sachet cutter is possible (through the provisions to integrate with pully/ hydraulic system, etc.), and it may be installed at some dedicated space on the shopfloor. Such mechanized operating requires a dedicated motor, pulley, and hydraulic/ pneumatic system. It is complex in construction and requires several other accessories/peripherals for its efficient operation, so it needs high capital requirements for its initial setup and subsequent working.

Discussion

The current research relates to the improvement activities on industrial shopfloors, particularly on the Indian FMCG shopfloor. It attempts to look deeply into industrial shopfloor activities and their associated ergonomics, production, and safety-related issues and then prioritize the areas of concern that must be addressed in the current instance. Once the area of critical concern was selected, it took up the challenge of providing a mitigating solution to address the safety-related issues that prevailed on the shopfloor of Indian FMCG units. The proposed mitigating solutions in the current research are based on the thorough implementation of ergonomics and design principles.

Salient Findings

- The majority of the research conducted in the industrial arena from an ergonomics perspective focuses on diagnosing the prevalence of MSDs and other ergonomic stressors. It does not provide mitigating solutions for the same, especially in an innovative product form.
- The research within the FMCG sector from an ergonomics perspective is almost negligible. The research in this sector is primarily focused on production/ operation excellence-related work aspects, especially the management-related attributes.
- Plenty of ergonomic stressors and safety-related issues prevail on the FMCG shopfloor and remain a great concern for shopfloor workers and factory management.
- The FMCG manufacturing units work at varied production scale levels. Yet, many non-standard unsafe work activities prevail on their shopfloor, and their intensity/ impact

varies according to the production/ operation scale. Context-specific innovative design solutions according to the varying needs and requirements are essential to devise mitigating solutions for the existing unsafe activities.

- Thorough implementation of ergonomic and design principles is instrumental in developing practical, innovative design solutions for improving the safety and well-being of those involved in unsafe activities on the FMCG shopfloors.

Testing of Hypothesis

Early at the preliminary ergo-audit of the FMCG manufacturing units, it was observed that the rework of pouches/ sachets is a prominent task/ job activity that exists upon every shopfloor engaged in manufacturing of FMCG goods, more particularly hair oil, shampoo, serum, etc. irrespective of the scale of production, number of workers employed, machinery involved, production strategies, etc. The researcher, at that very instance, predicted that if one is supposed to provide a mitigating solution in the form of an innovative design intervention, it can be very much apprehended that such a solution will be governed by the context-specific requirements of the production unit and their work parameters viz. scale of production, cost they want to incur on a solution, work requirements, etc. However, three varying levels of the mitigating solution (an innovative safety-enriched pouch/ sachet cutter) were developed to put it in the trial and determination phase. Those were step-by-step validated for their potential success at Factories A, B, and C, respectively.

The innovative tool developed for Factory A failed to cater to the needs of Factory B. The innovative tool developed as per the needs of Factory B was found successful on Factory B's shopfloor. However, it failed to cater to Factory C. Once the innovative tool, as per the context-specific needs of Factory C, was developed, the stakeholders received it well.

Novelties of the Study

- The literature indicates that the research carried out so far in the industrial sector from an ergonomics perspective remains limited to diagnostic studies, thereby proposing recommendations from the OSH perspective that include available standard guidelines (preventive measures, physical exercise, and therapy, rehabilitation measures, etc.) that may work for the betterment of occupational health. However, the current research is the first-of-its-kind research in a developing country's industrial sector that is not only a descriptive OSH-related study but also a prescriptive study with guidelines and real/

practical implementation of safety-enriched innovative products as mitigating solutions.

- The tools/ apparatuses developed to ensure safety for the selected unsafe activity, i.e., pouch/ sachet rework, have been developed considering three different scales of production level and associated attributes. This approach for product design and development of the tool/ apparatus addresses the same concern but for three different levels of production scale, which is unique, as reported in the current research.
- So far, the reported research has mainly been concerned with the standardized work activities and practices of the industrial shopfloor and has drawn maximum attention from the researchers. The current research picked up non-standardized work activity prone to injuries/ accidents and needs immediate attention. It also developed context-specific tools/ apparatuses to address unsafe work practices. This is probably a first-time approach for looking at and taking appropriate measures for unnoticed activities on the formal sector's industrial shopfloor.
- The current research is a good example wherein the designed and developed products have been protected for their Intellectual Property Rights (IPR) and implemented on an industrial shopfloor. All three innovative tools/ apparatuses have been protected from the IPR perspective both in terms of their design and utility.

Key Contributions

The current study depicts the overall journey of the innovative product from its pre-conceptual phase to its field trials and subsequent IPR protection, i.e., a systematic design approach based on ergonomic principles. Thus, it provides critical insights, guidelines, and strategies that other researchers may adopt to create and protect their innovation in varied industrial domains.

The methodology adopted within the current research generates awareness of ergonomics among various stakeholders in the FMCG domain. The ergonomic principles applied along with the systematic design strategy have been instrumental in providing mitigating solutions for varying levels of critical FMCG problems. As a deliverable, the present study provided three different innovative pouch/ sachet cutters that are well-suited to the specific requirements of the FMCG manufacturing units. They may adopt and use these safety-enriched pouch/ sachet cutters to enhance the safety of the rework activity. The developed tools can eliminate safety issues prevailing in pouch/ sachet cutting rework activity and eliminate drudgery. It leads to reduced man-day losses and worker compensation incurred due to accidents and injuries. These tools are easy to operate, maintain, and handle. Thus, these innovative tools can benefit industrial stakeholders significantly.

The current research has the potential to directly impact the well-being and safety of thousands of shopfloor workers engaged in rework activity that is prone to the inherent risks of cuts and injuries. It may generate a sense of security and be cared for by their factory management, and it may further build enhanced mutual trust among the employer-employee. Such studies may motivate factory management to conduct more such studies to improve the working conditions of the shopfloor and to remain productive by enhancing employee morale. The other researchers in the ergonomic field may also be encouraged to provide ergonomic design interventions as mitigating solutions by employing a systematic design approach, and they will not be limited to diagnosing and ascertaining the MSDs only and subsequent reporting.

Overall, aligned with the 'Zero Accident Vision' (Zwetsloot et al., 2017; Javed et al., 2021; Ahamad et al., 2022; OSHA, 2023), such practical studies on the industrial shopfloor help promote the philosophy and prove to be a proactive approach toward the advocates of this philosophy. It will greatly boost achieving this philosophy's bold vision and mission and motivate others to take up such research to accomplish it in record time.

Limitations and Future Scope of Work

- It is an in-depth field study based on the FMCG manufacturing units in northeastern India, particularly Assam. It has not explored the working conditions in the FMCG manufacturing units located in other parts of India. More new insights may have been gathered if those had been considered in this study.
- The current study has provided a mitigating solution in the form of a design intervention. It has not considered/ attempted to provide other types of mitigating solutions, viz. managerial solutions, behavioral solutions, engineering solutions, etc. Other solutions might be considered, and the approach towards their implementation may be explored further.
- The present study focuses on mitigating the 'after the fact' event occurrence, i.e., the situation arising after the pouch/ sachet gets defective and needs to be reworked. Efforts can be made to devise methods to minimize the event occurrence and its associated

negative consequences, i.e., methods to reduce the pouch/ sachet defects and subsequent rejection.

- Only the personal care goods (hair oil, serum, shampoo pouch/ sachets) were considered in this study. The FMCG segment covers other products filled in pouches/ sachets (jams, jellies, pickles, etc.), which are prone to the same ill effects. Explorations to devise innovative solutions for their reworking may also be explored.
- The field trials were conducted with a limited number of workers (as per availability) and as per the time constraint. Field trials were conducted as per 2-hour shifts for the ease of experimentation and various other logistic reasons. Efforts can be made to conduct field trials for an entire 8-hour shift, and more workers may be engaged (if available) to enlarge the sample size and consequent data collection.

Conclusion

This research has explored many OSH and productivity-related issues that prevail on the FMCG shopfloor and need immediate attention from researchers and other industrial unit stakeholders. The successful implementation of this research to address safety-related challenges of FMCG shopfloor has created awareness among factory workers and management about implementing ergonomic principles in the industry. The other researchers, industrial stakeholders, and others interested in promoting safety and well-being within industrial tasks may imitate and follow the methodology depicted in this current research to achieve their objectives. As this research methodology is well-depicted in a meticulous form moving forward in phases and sub-phases, it can be replicated easily by the researchers and others in an easy manner to cater to the needs of other issues prevailing in varied domains of industrial work.

Overall, the current research is a pioneering and novel work in the domain of FMCG manufacturing and related research, especially from an ergonomic perspective. It has successfully demonstrated the use of ergonomic and design principles to devise context-specific innovative solutions to the safety-related issues/ challenges that exist within the manufacturing operations and has proposed such solutions even for the varying levels of the production scale and associated needs. It is quite an appreciable attempt that paves the way for devising standardized solutions for non-standardized work activities and may motivate the OEMs to thoroughly look into the requirements of industrial activities that often remain neglected and need their attention and standardized devices/ tools/ apparatuses.

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LIST of ABBREVIATIONS

ABBREVIATION	FULL FORM
ANSI	American National Standards Institute
ASHRAE	The American Society of Heating, Refrigeration, and Air-Conditioning Engineers
ASSOCHAM	Associated Chambers of Commerce and Industry of India
BIP	Brahmaputra Industrial Park
BLS	Bureau of Labor Statistics
CAD	Computer-Aided Design
CAGR	Compound Annual Growth Rate
CHA	Chemical Hazard Analysis
CMIE	Centre for Monitoring Indian Economy Pvt. Ltd.
COVID-19	Coronavirus Disease
CTS	Carpal Tunnel Syndrome
DBT	Dry Bulb Temperature
DGFASLI	Directorate General Factory Advice and Labour Institutes
DHMS	Digital Human Modeling and Simulation
DMQ	Dutch Musculoskeletal Questionnaire
ECG	Electrocardiograph
EDRs	Electrodermal Responses
EEG	Electroencephalograph
EMG	Electromyograph
EPIP	Export Promotion Industrial Park
ERP	Enterprise Resource Planning
ETA	Event Tree Analysis
FDI	Foreign Direct Investment
FMCG	Fast Moving Consumer Goods
FMEA	Failure Mode and Effect Analysis
fMRI	Functional Magnetic Resonance Imaging
FTA	Fault Tree Analysis

FY	Financial Year
GDP	Gross Domestic Product
GSR	Galvanic Skin Response
GST	Goods and Services Tax
GT	Globe Temperature
HAL	Hand Activity Level
HAV	Hand and Arm Vibrations
HAZAN	Hazard Analysis
HAZOP	Hazard and Operability Study
HF	Human Factors
HR	Heart Rate
HRV	Heart Rate variability
IAQ	Indoor Air Quality
IBEF	India Brand Equity Foundation
IDC	Industrially Developing Countries
IIP	Industrial & Investment Policy of Assam
IIT	Indian Institute of Technology
ILO	International Labor Organization
IMF	International Monetary Fund
IoT	Internet of Things
ISO	International Organization for Standardization
JIT	Just in Time
JSQ	Job Stress Questionnaire
MEG	Magnetoencephalography
MFA	Muscle Fatigue Assessment Method
MMH	Manual Material Handling
MOST	Maynard's Operation Sequencing Technique
MSDs	Musculoskeletal Disorders
MSME	Micro Small and Medium Enterprises
MTM	Method-Time-Measurement

MWW	Mean Weight Workload
NASA-TLX	National Aeronautics and Space Administration – Task Load Index
NDA	Non-disclosure Agreement
NEIDS	North East Industrial Development Scheme
NEIPP	North-East Industrial and Industrial Promotion Policy
NIOSH	National Institute of Occupational Safety and Health
NMQ	Nordic Musculoskeletal Questionnaire
OCRA	Occupational Repetitive Action
OEE	Overall Equipment Efficiency
OEM	Original Equipment Manufacturers
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Administration
OWAS	Ovako Working Posture Analyzing System
PHA	Preliminary Hazard Analysis
PPE	Personal Protective Equipment
RCA	Root Cause Analysis
REBA	Rapid Entire Body Assessment
RFID	Radio Frequency Identification
RULA	Rapid Upper Limb Assessment
SKU	Stock Keeping Units
SLM	Sound Level Meters
SMEs	Small and Medium Enterprises
SUS	System Usability Scale
TOR	Technique of Review
TQM	Total Quality Management
TWA	Time Weighted Average
USA	United States of America
USD	United States Dollar
VSM	Value Stream Mapping
WBGT	Wet Bulb Globe Temperature

WBT	Wet Bulb Temperature
WBV	Whole Body Vibration
WEF	World Economic Forum
WMSDs	Work-related Musculoskeletal Disorders
WRUE	Work-related Upper Extremity
WSQ	Work Style Questionnaire
ZAV	Zero Accident Vision

In the current thesis, the approximate value (used throughout) of 1 USD = 83 INR.

1

Introduction

Abstract

Ergonomics and Occupational Safety and Health (OSH) promotion initiatives play a vital role in improving well-being and safety on industrial shopfloors worldwide. Researchers have looked into industrial shopfloor improvements utilizing several approaches in diverse industrial sectors. The Fast Moving Consumer Goods (FMCG) sector, dwelling on highly-paced assembly lines and manufacturing low-cost- high-volume products, has received scanty research from an ergonomics perspective. The majority of research in this sector remains focused on achieving production and operation excellence. OSH scenarios, especially the safety-related jobs and activities peculiar to the FMCG work parameters, need to be explored to better address the adverse working conditions prevailing on the FMCG shopfloors. Scanty research has been carried out concerning OSH issues within Indian FMCG manufacturing units, which is the focus area of this research. This chapter discusses the importance of FMCG, ergonomics, and OSH-related research in diverse industrial sectors, research motivation, the background of the research area, research gaps, research questions, problem statement, and aim & objectives are discussed.

1.1 Background/ Present Scenario

In a modern world economy, any country's economic and social growth depends upon its three pillars: the agricultural, industrial, and service sectors. It is essential to keep these sectors running smoothly and growing excellently to keep the country dwelling and progressing at a decent rate generally determined by its Gross Domestic Product (GDP) growth (World Bank, 2023; ILO, 2024; IBEF, 2024). To keep an eye on the parameters of economic development, economists and economy-related researchers continue to conduct their research. Extensive research into the work parameters related to agriculture, industry, and service sectors also remains the primary concern of the researchers to identify lacunae, devising appropriate corrective measures to improve these sectors and contribute to the nation's growth. For example, in the industrial sector, several researchers tend to work and focus on improving production, management, and Occupational Safety and Health (OSH) related concerns to benefit the stakeholders involved (ICOH, 2024; WHO, 2024). OSH-related research remains the primary concern in the industrial sector of developing nations and generally receives lesser attention within the Industrially Developing Countries (IDCs) (McNeill, 2000; Benjamin, 2001; O'Neill, 2005; Scott, 2009; Shahnavaz, 2009; Berhan, 2020; Jilcha, 2023).

International Labor Organization (ILO) defines OSH as the science of the anticipation, recognition, evaluation, and control of hazards arising in or from the workplace that could impair the health and well-being of workers, taking into account the possible impact on the surrounding communities (Alli, 2008; Reese, 2017; ILO, 2024) and the general environment and proactively advocates for promoting and improving OSH conditions within varied work domains to promote well-being within the industrial workforces (Holt and Allen, 2015; ILO, 2024). Apparently, OSH-related research is instrumental in improving shopfloor working conditions and promoting workers' well-being and productivity thereof (Alford et al., 2014).

The industrial sector typically consists of various sectors: durable goods manufacturing, electronic goods manufacturing, Fast Moving Consumer Goods (FMCG) manufacturing, etc. Among these, the FMCG sector is an important contributor to every country's economic growth. FMCG is an essential part of day to day life of every person across the globe and accounts for more than half of all consumer spending (Kiran Sable, 2019; Singh and Karmakar, 2021; IBEF, 2023). It comprises products such as food & beverages, over-the-counter drugs, health care products, and other products such as personal care, toiletries, and home care products.

Especially in India, the FMCG industry is the fourth largest sector in the Indian economy and employs around 3 million people, accounting for approximately five percent of the total factory employment in India (Neena Prasad, 2019; CMIE, 2020; IBEF, 2023; ASSOCHAM, 2023). The FMCG sector has grown rapidly from 31.6 billion USD in 2011 to 52.75 billion USD in 2018 (Nielsen, 2021). The total revenue of the FMCG market is expected to grow at a Compound Annual Growth Rate (CAGR) of 27.9% from 2021 to 2027, reaching nearly USD 615.87 billion (IBEF, 2024).

The Indian FMCG sector remains competitive due to the presence of multinational companies, domestic companies, and unorganized sectors (Aparna, 2018). By adopting various strategies to stay competitive, FMCG companies tend to increase revenues and expand their customer base year after year (Jayanthi R., 2017), influencing every citizen daily. In the context of OSH in the FMCG sector, minimal information is available from the published research and is known mainly from the food and beverages segment (Spellman and Bieber, 2008; Nivedita Bhushan, 2011; Singh and Karmakar, 2021). As the overall FMCG sector covers a highly diversified range of manufacturing activities, the paucity of literature about OSH in FMCG poses a severe challenge for the studies to be undertaken by researchers in this domain. Typically, the major issues that prevail in the food and beverage manufacturing/ processing units comprise slips, trips, and falls due to wet, slippery floors, ergonomic issues, high/ cold temperature exposure, use of sharp cutting tools, especially in meat cutting units, chemical exposure, etc. (Shizue Tomoda, 1993; Alli, 2008; Spellman and Bieber, 2008; ILO, 2023, BLS, 2024). Such safety-related issues negatively impact the shopfloor workers and become a prime concern for the factory management as these have several ill effects that negatively affect the worker morale and productivity. Currently, the OSH issues concerning FMCG manufacturing industries engaged in household/ personal care products (toiletries, detergents, shampoo, hair oil, etc.) and health care products (over-the-counter drugs) remain less explored.

The FMCG manufacturing concerns, work activities, associated OSH scenario, safety-related issues, and challenges have not been adequately explored and documented in any research, especially from an ergonomics perspective. Therefore, the current study broadly deals with exploring the FMCG manufacturing shopfloor job/ activities from an ergonomics perspective, identifying the various issues/ challenges prevailing on the FMCG industrial shopfloor, prioritizing the critical area of concern and proposing innovative mitigating solutions to improve the work activities prone to safety-related issues (the selected critical area of concern).

To identify the research gap and corresponding research questions pertaining to ergonomic stressors and OSH scenarios in the Indian FMCG sector, the whole gamut of literature has been summarized below.

1.2 Summary of Literature Review

A summary of the relevant and closely associated topics is presented in the following sub-sections for a quick understanding and to have an immediate connection with the research topic under consideration. However, a detailed discussion of these topics is discussed in Chapter 2.

1.2.1 Fast Moving Consumer Goods (FMCG)

FMCG are low-priced items used with a single or limited number of consumption occasions (Baron et al., 1991) and are sometimes referred to as consumer packaged goods or groceries. FMCG comprises three major product segments: food, beverage, and household (Key Note, 2006; IBEF, 2024). FMCG is an essential part of day to day life of every person across the globe and accounts for more than half of all consumer spending (Kiran Sable, 2019; Dinesh et al., 2023; IBEF, 2024). It comprises products such as food & beverages, over-the-counter drugs, health care products, and other products such as personal care, toiletries, and home care products. In the present highly competitive and dynamic global market, the global FMCG market has witnessed significant growth owing to lifestyle changes, demographic variations, an upsurge in organized retail, a rise in disposable income, and an increase in urbanization (ASSOCHAM, 2023).

1.2.2 Importance of FMCG

Over the past two decades, the FMCG industry has witnessed tremendous growth patterns globally (World Bank, 2023; IBEF, 2024). The FMCG industry thus makes a significant contribution to the world economy. It has been the most critical contributor to the GDP of every country globally and is also the major employment source within these countries. For instance, in the U.K., the FMCG industry employs over 16% of the total workforce and contributes over 8% of the U.K.'s GDP (Bourlakis and Weightman, 2004; Francis et al., 2006; Aljunaidi and Ankrah, 2014). Interestingly, it is the largest sector in New Zealand, wherein food and beverage manufacturing is the largest manufacturing sector, representing 45% of total manufacturing income, and it directly or indirectly employs more than 4,93,000 people – one in five of the workforce (New Zealand Food & Grocery Council, 2023).

Indian FMCG sector is the fourth largest sector in the country, and it employs around 3 million people, accounting for approximately 5% of the total factory employment (IBEF, 2024). In Saudi Arabia, although the country's economy is heavily dependent on the oil industry, which represents 60% of total investments in the industrial sector, FMCG stands as the third largest industry in the country with 11% of total investments in the industrial sector (Al-Eqtisadiah, 2010). Similarly, the FMCG sector has been growing in the United States of America (USA), contributing to nearly 6% of the country's GDP (The Sterling Choice, 2023). Asia-Pacific is also expected to grow at the highest CAGR of 8.0% during 2019 - 2025, owing to changes in lifestyles led by globalization and an increase in the working population (Kiran Sable, 2019; IMF, 2023).

1.2.3 Occupational Safety and Health (OSH) scenario in the FMCG sector

ILO defines OSH as the science of the anticipation, recognition, evaluation, and control of hazards arising in or from the workplace that could impair the health and well-being of workers, taking into account the possible impact on the surrounding communities (Alli, 2008) and the general environment and proactively advocates for promoting and improving OSH conditions within varied work domains to promote well-being within the industrial workforces (ILO, 2023). In the context of OSH in the FMCG sector, minimal information is available from the published research, and it is available mainly from the food and beverages segment (Spellman and Bieber, 2008). As per the reported data by the U.S. Bureau of Labor Statistics (BLS), the workers in food manufacturing are more likely to be fatally injured and experience non-fatal injuries and illnesses than workers in other industries as a whole (Nivedita Bhushan, 2011; BLS, 2024). For instance, the food processing sector reported 93,200 incidents of recordable illness and injuries in 2008, translating to 6.2 cases per 100 full-time workers. This was 59% greater than the other industry rate of 3.9 and higher than the manufacturing sector rate of 5.0 instances (BLS Statistics, 2008). As the overall FMCG sector covers a highly diversified range of manufacturing activities, the paucity of literature pertaining to OSH in FMCG poses a severe challenge to the studies to be undertaken by the researchers in this domain. Typically, the major issues that prevail in the food and beverage manufacturing/ processing units comprise slips, trips, and falls due to wet, slippery floors, ergonomic issues, high/ cold temperature exposure, use of sharp cutting tools, especially in meat cutting units, chemical exposure, etc. (Shizue Tomoda, 1993; ILO, 2023; BLS, 2024). OSH issues concerning FMCG manufacturing industries engaged in household/ personal care products (toiletries, detergents, shampoo, hair oil, etc.) and health care products (over-the-counter drugs) remain less explored (Singh and Karmakar, 2021).

1.2.4 OSH: current trends, legal compliances, and innovation

In the current era of Industry 4.0, there is a prominent hue and cry for achieving a 4.0 factory scenario wherein there will be zero injuries/ accidents because there are zero workers (Zwetsloot et al., 2017; Javed et al., 2021; Ahamad et al., 2022). However, this remains a distant dream, particularly within IDCs like India, China, Sri Lanka, Korea, Ethiopia, etc., as automation in their manufacturing sector is not rapidly possible owing to several challenges, viz. monetary, technology, legal compliances, employment generation, etc. (De Silva et al., 2017; Narain et al., 2021, Jilcha, 2023). Practically, the underlying premise of the Zero Accident Vision (ZAV) is that all (severe) accidents are avoidable. In order to attain safety excellence, ZAV is then the goal and dedication to establishing and guaranteeing safe work environments and stopping all (severe) incidents. This is a lofty objective that frequently leads to several misconceptions that see ZAV as a "goal" of zero accidents as opposed to a "journey" and a "process" of developing safe work (safety excellence) (Zwetsloot, 2017; Moller et al., 2018; Garcia, 2019). Concerning FMCG, in developed nations, food and beverage manufacturing, personal care products, and healthcare product manufacturing remain highly automated. However, in developing nations, most household/ personal care products and healthcare product manufacturing rely on semi-automated manufacturing, often employing many workers, and is prone to work-related injuries/ accidents (Singh and Kamakar, 2023). Through their legal framework and compliance guidelines, several statutory organizations/ professional bodies (like ILO, International Organization for Standardization (ISO), Factories Act 1948, etc.) advocate, promote, and regulate the OSH scenarios within the industrial sectors.

These regulations are becoming stringent daily, and their compliance and adherence are becoming strict and compulsory (Ministry of Labour and Employment, Govt. of India, 2020; Jain and Jain, 2021; DGFASLI, 2024), as evident from the guidelines and provisions of the Occupational Safety, Health, and Working Conditions Code, 2020 (OSHWC Code, 2020). Although adhering to statutory legal compliance is an utmost urgency for modern manufacturing units, there remain a few lapses towards their full compliance due to several reasons, viz. ignorance towards the scientific areas that require research orientation, paucity of available time for non-routine works, non-availability of experts in the domain, industry-curricula gap, etc. (Singh and Karmakar, 2022, ILO, 2023, Rajat Choudhary, 2023). In the wake of such a situation, the industry owners/ business houses may take advantage of the tremendously ongoing research-based innovation culture/ regime worldwide. Currently, research-based innovation related to almost every aspect of manufacturing has been practiced in the industrial sector, especially in developed nations (Galanakis, 2021; Obradović et al., 2021; Draghici and Ivascu, 2022). A clear correlation between innovation and success in growing revenues, better OSH scenarios, and well-being has emerged in modern times. In breakthrough innovation and growth, the most innovative companies overall are growing significantly faster than the least innovative. This difference for industrial manufacturing companies is dramatic (Mannebach, 2021; Runiewicz-Wardyn, 2022). The manufacturing sector's most innovative companies grew 38% over the last three years - nearly 12% per year - while the least innovative managed just 10% growth over the same period (PwC, 2023). Learning from such research studies conducted and ongoing, researchers in developing nations can also proactively help the manufacturing sector promote OSH culture through innovation and research.

1.3 Scope of Work in the FMCG Sector

From the discussions carried out in the previous sub-sections, it is pertinent to note the importance and impact of the FMCG sector on the daily life of every human globally. It was also discussed that FMCG manufacturing is multi-varied and faces several challenges from the production/ operation and OSH point of view. There lies a dire need to explore FMCG working and address the various production/ operation and OSH-related issues in the context of the FMCG sector as it remains an unexplored sector by researchers worldwide. Researchers have conducted ample research in various manufacturing sectors, especially in durable goods manufacturing, and have researched various work domains to analyze, mitigate, and improve working conditions (Karmakar and Solomon, 2018; Sanjog et al., 2019). Notably, the research on various ergonomics aspects, including OSH, has been less explored in the context of developing countries, including India. In the Indian scenario, while ergonomics research has been carried out in diverse industrial sectors, studies in the context of FMCG sectors remain unexplored. The FMCG manufacturing units are rapidly expanding to Tier II and Tier III Indian cities owing to government support and policies. The northeastern Indian states, especially Assam, have witnessed the rapid establishment of Indian FMCG manufacturing units supported by government subsidy and tax rebate schemes (NEIPP, 2007; NEIDS, 2017; IIP, 2019).

This sub-section attempts to assess the need and determine the scope of 'Ergonomic and OSH Interventions' in the FMCG sector to improve existing shopfloor conditions to enhance productivity and efficiency as well as to ensure the safety, occupational health, and well-being of the FMCG workers.

1.3.1 Ergonomic design interventions

Available literature in regard to improving manufacturing units/ workplaces suggests 'Ergonomic Design Interventions' as a potential solution to mitigate adverse workplace-related situations (Gangopadhyay and Dev, 2014; Sanjog et al., 2015; Neri et al., 2022). Researchers have suggested context-specific recommendations in shopfloor layouts and design interventions for workstation design implementation in various industrial domains. However, scanty research of such sort exists for the FMCG sector (Pérez-Gosende et al., 2021; Nguyen et al., 2022). In the context of manufacturing industries, particularly assembly lines of heavy industries (e.g., the automobile industry), are already standardized and, in many cases, fully automated/ semi-automated; thus, the information regarding workstation redesign and work accessories redesign is rarely available (Singh and Karmakar, 2023). Whatever design interventions have been proposed in those assembly lines are not adaptable in the FMCG sector due to the nature of work in FMCG, which engages both skilled/ non-skilled unisex labor and is particularly semi-automated. Kushwaha and Kane, 2016 proposed a workstation design for a shipping crane cabin in the steel industry. Ganesh et al., 2019 devised a design intervention for the footwear industry in India. Few researchers have also proposed ergonomic design interventions to improve OSH and productivity-related issues in part assembly-related work, viz. pump assembly, etc. (Binoosh et al., 2017; Bortolini, 2023), that is, context-specific work. Such context-specific ergonomic design interventions (Sain and Meena, 2016) addressing various issues of the workstation and work accessories, and innovative tools can be introduced in FMCG industries to improve their productivity, efficiency, and worker well-being.

The researchers and engineers may thoroughly examine the indispensable continuous improvement activities (Kaizens) related to in-house fabricated furniture (workbenches, chairs, and stools). It would help them design and manufacture those per the distinct anthropometric needs of the working population engaged in such production units with proper consideration of ergonomic principles (Prabir Mukhopadhyay, 2022). It will have a high impact and an immediate effect on curbing the prevailing OSH and Work-related Musculoskeletal Disorders (WMSDs) issues. Research may be initiated to address anthropometric mismatch-related areas, viz. assembly line heights, workstation clearances from worker bodies, etc. Moreover, model assembly lines may be commissioned based on the implications drawn from such studies and ergonomic evaluations (Prabir Jana, 2020; Singh and Karmakar, 2022; Singh and Karmakar, 2023).

1.3.2 Standardization of work activities

Further, it is interesting to note that the successful production strategies of the automotive sector, like lean manufacturing (Alkhoraif et al., 2019; Karmen Pažek, 2021), are being implemented into the FMCG sector without thorough investigations about its results and consequences when applied to FMCG work (Singh and Karmakar, 2022). Continuous improvements (Kaizen) are being implemented without considering ergonomic principles in FMCG assembly line-related work, negatively impacting the engaged workers (Singh and Karmakar, 2023). Various work standardization approaches viz. Maynard's Operation Sequencing Technique (MOST) and Method-Time-Measurement (MTM) are being implemented in the automotive and processing industry for work measurement and productivity enhancement (Kuhlang et al., 2011; Tuan et al., 2014; Puvanasvaran et al., 2018). However, their relevance to FMCG work and their efficacy in FMCG work are not known. Overall Equipment Efficiency (OEE) is the single limited approach being used in FMCG work to determine production efficiency (Puvanasvaran et al., 2016; Singh and Karmakar, 2022).

Workers perform their tasks from both sides of the assembly line in FMCG sectors (unlike other assembly lines of heavy industries) (Thain and Bradley, 2014). Hence, rigorous research is needed to be conducted to find the best possible spatial arrangement considering both the workers' hand dominance and the requirement of work accessories across such assembly lines to capture the motion economy and enhance productivity (Dempsey et al., 2010; Dianat et al.; 2017). The researchers/ shopfloor engineers may take up appropriate work-standardization assorted techniques considering ergonomic principles to optimize the productivity of FMCG shopfloors. The efficacy of the implemented ergonomic interventions could be studied in terms of method study/ motion study techniques on FMCG shopfloors. From the extrapolations of such studies, the best feasible man-machine ratio, pacing rate of assembly lines, and adequate rest pauses may be determined to enhance productivity while ensuring OSH and the well-being of the workers engaged in FMCG shopfloors. Kaizen activities with proper ergonomic considerations must be executed in totality and not in a fragmented manner (considering each workstation as a distinct output driver) in the FMCG assembly line. All such activities must be done in consideration with all stakeholders involved, viz. production, operation, maintenance, and safety divisions of the concerned FMCG manufacturing units (Singh and Karmakar, 2022; Singh and Karmakar, 2023).

1.3.3 Ergonomic stressors and OSH

Several researchers have conducted research on investigating the prevalence of several ergonomic stressors and their associated risks in assembly line-related work (Delleman et al., 2004; Colombini and Occhipinti, 2006; Shin and Park, 2019), but little effort has been given to propose/ offer 'design ergonomic interventions' as potential solutions to address those WMSD-related problems successfully (Singh and Karmakar, 2021). Specific ergonomic stressors related to FMCG assembly line work, viz. prolonged standing, high repetition of upper extremities, long work hours, monotonous job work, and man-machine pacing mismatch, have rarely been addressed in FMCG industries. Considering a critical industrial work-related issue, i.e., industrial accidents, injury rate, and worker compensation, the industries do not reveal much information (Pransky et al., 1999; Philipsen, 2009; Zwetsloot et al., 2013; Noman et al., 2021; Kyung et al., 2023). The information related to such matters is almost negligible in all sectors banking upon assembly line-related work. The available literature on OSH issues focuses on hazard identification, surface layer accident investigations, job satisfaction levels, and worker well-being (Sklet, 2004; Dahlke, 2015; Rout and Sikdar, 2017; Gan, 2019; Dempsey, 2021). Much deeper context-specific hazard identification/ elimination, accident investigations/ mitigation, and negative work-related consequences in the FMCG sector are unknown, and mitigation strategies adopted to curtail those thus remain hidden (Singh and Karmakar, 2022; Singh and Karmakar, 2023).

Innovative tools may be designed and developed to aid the assembly line-related work in FMCGs and to ensure safety in injury-prone unsafe/ non-standard work practices. Standard work practices and various work training methodologies may further be explored to improve the OSH and well-being of workers engaged in FMCG manufacturing work. Rigorous research may be carried out to address various health, hygiene, housekeeping, and slippery floor management issues to improve the shopfloor conditions prevailing in FMCG manufacturing units (Singh and Karmakar, 2024).

1.4 Research Gap and Research Questions

The existing literature pertaining to the research carried out in the purview of ergonomics, OSH, and manufacturing/ production/ industrial improvements across industrial sectors worldwide reveals several factors about the global and Indian FMCG sectors. A careful observation and minute study of the existing literature provides deep insights into the current scenarios within the global and Indian manufacturing industry, especially about the FMCG sector in the context of ergonomics and OSH. The main inferences that can be drawn from this literature review are summarized below:

- The FMCG sector in India, especially in Assam, is the most emerging industrial sector owing to the Central Government of India and Assam Government policies/ schemes.
- Ergonomics and OSH play a vital role in ensuring and promoting worker safety as well as raising productivity.
- Lesser knowledge of ergonomics and OSH prevails among Indian manufacturing sectors, and they remain unaware of the benefits of ergonomics and OSH.
- The majority of the research conducted in the field of ergonomics and OSH focuses on investigating the prevalence of several ergonomic stressors and their associated risks; little effort has been given to propose/ offer 'design ergonomic interventions' as potential/ mitigating solutions.
- Scanty research has been carried out in the field of FMCG that can also be classified into the fields of production/ operation and management-related aspects; focus on ergonomic and OSH issues in FMCG is almost negligible.
- Paced assembly lines and the prevalence of several context-specific unsafe activities due to the non-availability of adequate tools and non-standard work activities are the common features of the FMCG or make-and-pack industry.
- Successful production strategies of the automobile sector, like lean manufacturing, are being implemented in the FMCG sector without thorough investigations into its results. Continuous improvements (Kaizen) are being implemented without consideration of ergonomic principles.
- In the Indian scenario, ergonomics and OSH-related research are mainly dedicated to the durable goods manufacturing sector working in the micro, small, and medium sectors, and various context-specific recommendations in the context of shopfloor layouts and design interventions for workstation design have been suggested.
- Research within the Indian FMCG sector is mainly concentrated on management aspects, and there is no reported study on this sector from an ergonomics and OSH perspective. Ergonomic stressors and OSH hazards related to paced assembly, spatial arrangements of workers across paced assembly lines, hazardous risk factors, and efficacy of work measurement tools have not been studied in the context of the FMCG industry.

From the literature review, it is evident that no reported study from the ergonomics and OSH perspective focussed on improving shopfloor conditions and addressing safety-related issues in the Indian FMCG industry exists till date. Several aspects related to OSH, standardization of work activities, and design ergonomic interventions have been explored by researchers to improve the shopfloor working conditions of durable goods manufacturing industries, but many of such vital factors remain unexplored in the FMCG industrial workplaces. A few of these unexplored factors are summarized in the schematic diagram (Figure 1.1), and these gaps in the context of the FMCG shopfloor activities/ operations lead to several research questions that must be explored and answered to improve the shopfloor working conditions existing in Indian FMCG manufacturing industries.

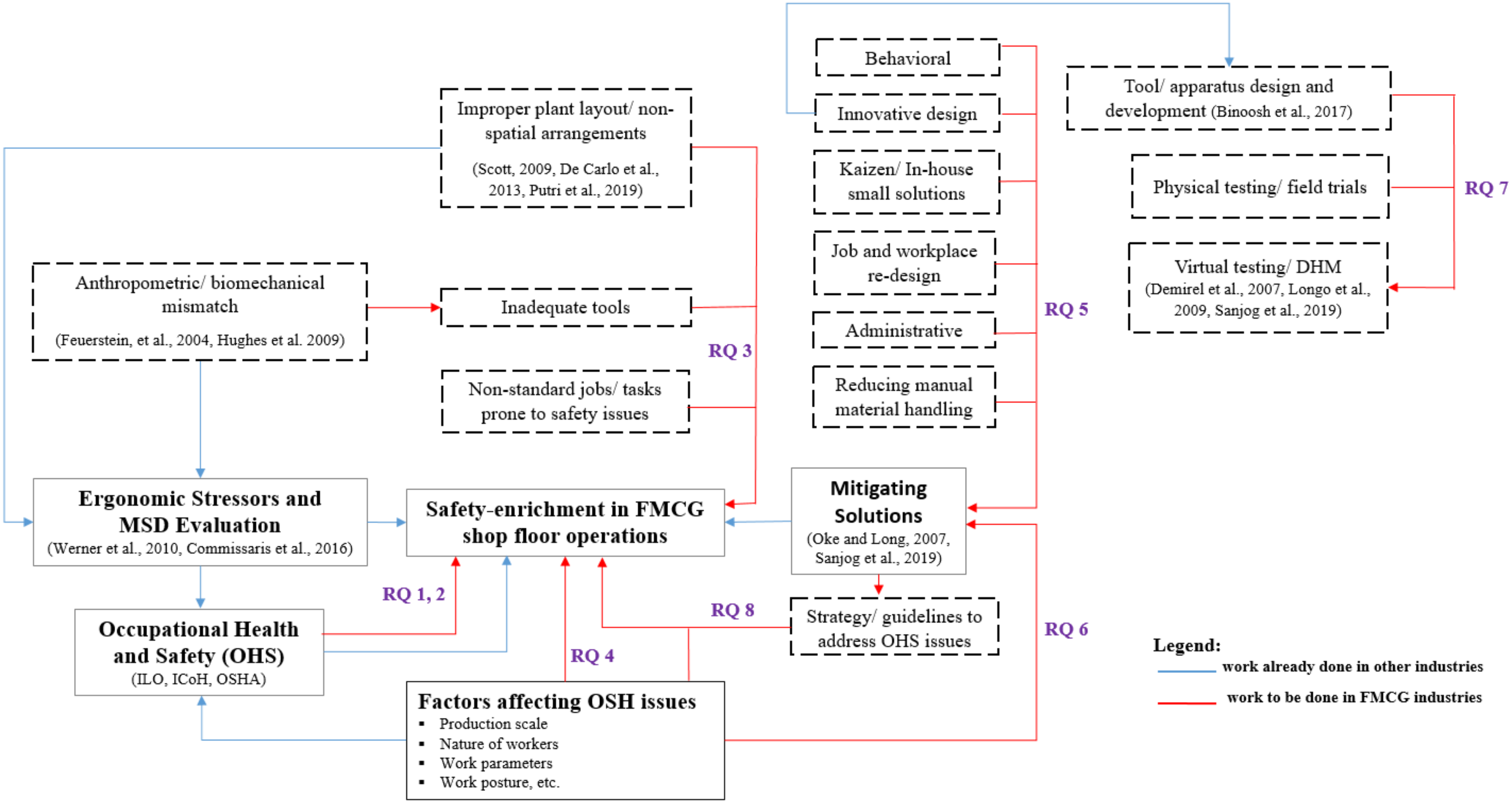


Figure 1.1: Research gap: Schematic diagram. (Source: author)

From Figure 1.1, the following eight research questions associated with the research gaps have been extracted:

R.Q. 1: What are the current trends of ergonomic-related research and its corresponding ergo tools/ techniques used in diverse Industrial setups?

R.Q. 2: What are the various OSH-related issues prevailing at manual/ semi-automated Indian FMCG manufacturing units?

R.Q. 3: Which area of concern from OSH purview must be prioritized according to the shopfloor workers, manager/ supervisors, and factory management?

R.Q. 4: What are the various criteria or considerations to be taken care of for addressing the identified OSH-related issues in the FMCG shopfloor?

R.Q. 5: What could be the most feasible solution to address identified OSH-related issues in the FMCG shopfloor from the ergonomics perspective?

R.Q. 6: Will the same solution be applicable/ implementable for different scales of production/ production levels in the FMCG production process?

R.Q. 7: How can the implemented solution be tested/ justified?

R.Q. 8: What should be the actionable framework to address OSH-related issues for factory shopfloors with different scales of production?

1.5 Problem Statement

A detailed analysis of the available literature reveals the paucity of ergonomics-related research looking into the OSH aspects in an industrial scenario, especially in FMCG sectors. Reported scanty research directed towards OSH mainly deals with issues in shopfloor production processes and assembly-related work of varied industrial setups. Such research generally focuses on considering the standardized work practices of the respective domain. Ergonomic study on FMCG industrial shopfloor is rarely explored and deserves immediate attention, realizing its high potential for generating employment and enhancing GDP across the globe.

An ergo-audit conducted at twenty FMCG manufacturing units revealed the presence of various ergonomic stressors, bottlenecks to productivity, and safety-related issues. As per a unanimous opinion, all the stakeholders (shopfloor workers/ safety in charge/ factory management) considered the non-standardized work activity of reworking defective pouches/ sachets as the critical area of concern. Due to the non-availability of standard tools, the current rework activity involves using sharp cutters/ blades held in bare, slippery hands. It is prone to nicks, cuts, and injuries, posing a safety concern. In addition, it challenges factory management to adhere to basic safety compliance. Besides, the forceful manual hand squeezing of the cut pouch/ sachets to extract in-filled liquid leads to drudgery and contamination. Being a non-standardized work activity, no Original Equipment Manufacturer (OEM) has looked into the concerns of this activity. Although knowing the safety concerns involved in this activity, the stakeholders are compelled to resort to using inadequate tools in varied work conditions. There is a dire need to develop innovative safety-enriched tools/ apparatus as a mitigating solution. Such tool/ apparatus must be capable of eliminating the use of sharp cutter/ blade in bare, slippery hands and eliminate manual hand squeezing. It will help promote safety and well-being in such rework activities.

1.6 Motivation and Justification for Choosing the Present Research

In the recent past, northeastern Indian states, especially Assam, have witnessed the rapid establishment of Indian FMCG manufacturing units owing to government subsidy and tax rebate schemes (NEIPP, 2007; NEIDS, 2017; IIP, 2019). Many Indian FMCG business groups manufacturing personal care FMCG goods have expanded their manufacturing units in Assam, providing tremendous growth opportunities for manufacturing and employment generation. These Indian FMGG manufacturing units are highly fragmented into mega, large, small, and medium scales. These might be prone to traditional human-machine incompatibilities, as reported by various researchers in the context of other micro, small, and medium enterprises (Vethirajan, 2014; Aparna, 2018; Singh and Karmakar, 2022). Such industries commonly ignore ergonomics (the science of human-machine compatibility) (Sanjog et al., 2016).

Foreseeing the tremendous growth of Indian FMCG and its associated high employment generation perspectives in the northeastern region and its contribution to the nation's GDP, it is the right time to conduct investigations from an ergonomic perspective in the existing workplaces of these industries to improve the existing shopfloor conditions. Such research aiming to improve OSH scenarios employing innovation-based strategies may benefit stakeholders.

The initial exploration of the FMCG shopfloor in such units revealed the presence of several ergonomic stressors, bottlenecks to productivity, and safety concerns. Prolonged standing and working with highly repetitive motions and awkward posture adoption are the common features of such shopfloors. Kaizen (continuous improvement activities, in-house fabricated furniture and accessories, tools, and fixtures) is being implemented without consideration of ergonomic principles, leading to various OSH issues. Improper spatial arrangements and orientation of workers and work accessories across the assembly lines are prominent, thereby negatively affecting productivity. Prominently, the peculiar non-standardized activity prevailing on FMCG shopfloors involves inadequate/ sharp-edged tools, wet-slippery floors and associated housekeeping, and heavy manual load handling, which are commonly visible on shopfloors. Rework of the defective pouch/sachet is one such critical non-standardized activity involving inadequate tools/ apparatus, leading to safety-related issues.

Rework of defective pouches/ sachets is typically performed using sharp cutters/ blades held in bare, slippery hands and manual hand squeezing. It is prevalent among all FMCG manufacturing units that manufacture personal care products like hair oil, serum, shampoo, etc. Considering the importance and severity of the safety concerns in FMCG rework activities, there lies an immediate need to provide mitigating solutions practically in the form of innovative tools/ apparatus as ascertained during ergo-audit and subsequent prioritization of the critical area of concern with the stakeholders. Such tools/ apparatus could help address the existing safety issues, promote safety, reduce drudgery, and promote the workers' well-being in rework activities.

1.7 Aim and Objectives

Aim: The current research aims to address the safety-related issues in the FMCG shopfloor through ergonomic design and the development of innovative tools/ devices constrained by the scale of production, cost, and available resources.

Objectives: In order to fulfill the aim of the current research, the following objectives were set to achieve the goal:

- To understand the state-of-the-art literature on ergonomic issues and the implementation of ergonomic interventions in diverse industrial sectors.
- To study the OSH-related issues in the Indian FMCG shopfloor.
- To identify the most critical areas of concern in the context of work/ worker safety.

- To design and develop innovative context-specific ergonomic design interventions as a mitigating solution.
- To evaluate the efficacy of the developed innovative design interventions.
- To propose a framework for developing safety-related design interventions for the factory shopfloor.

1.8 Hypothesis

Hypothesis 1 (Q1 – Q8): The design and development of innovative tools/ devices in the context of OSH on the shopfloor of the FMCGs is constrained by the scale of production, cost, and available resources.

1.9 Expected Outcome

The outcomes of the current research came up in the form of both tangible and non-tangible outputs having due consideration of ergonomics, design, and safety aspects, as listed below:

- The tangible output came in the form of the three (03) different context-specific safety-enriched tools for the sachet/ pouch rework activity that were developed as per the intended requirement of each industrial unit constrained by their production, cost, and available resources.
- The intangible output came in the form of a framework that may be used by the prospective engineers, supervisors, and researchers planning to devise innovative design interventions to address the safety-related issues on the shopfloor of their respective industrial units. Such a framework proposes an executable approach to develop safety-related design interventions for the factory shopfloor working within various industrial segments.

1.10 Framework of Thesis

The current research is presented in a thesis form comprising seven chapters based on the study workflow. The following Figure 1.2 briefs about the thesis workflow, and the corresponding Table 1.1 summarizes the research questions, objectives, and associated scholarly outcomes as addressed in the individual chapters.

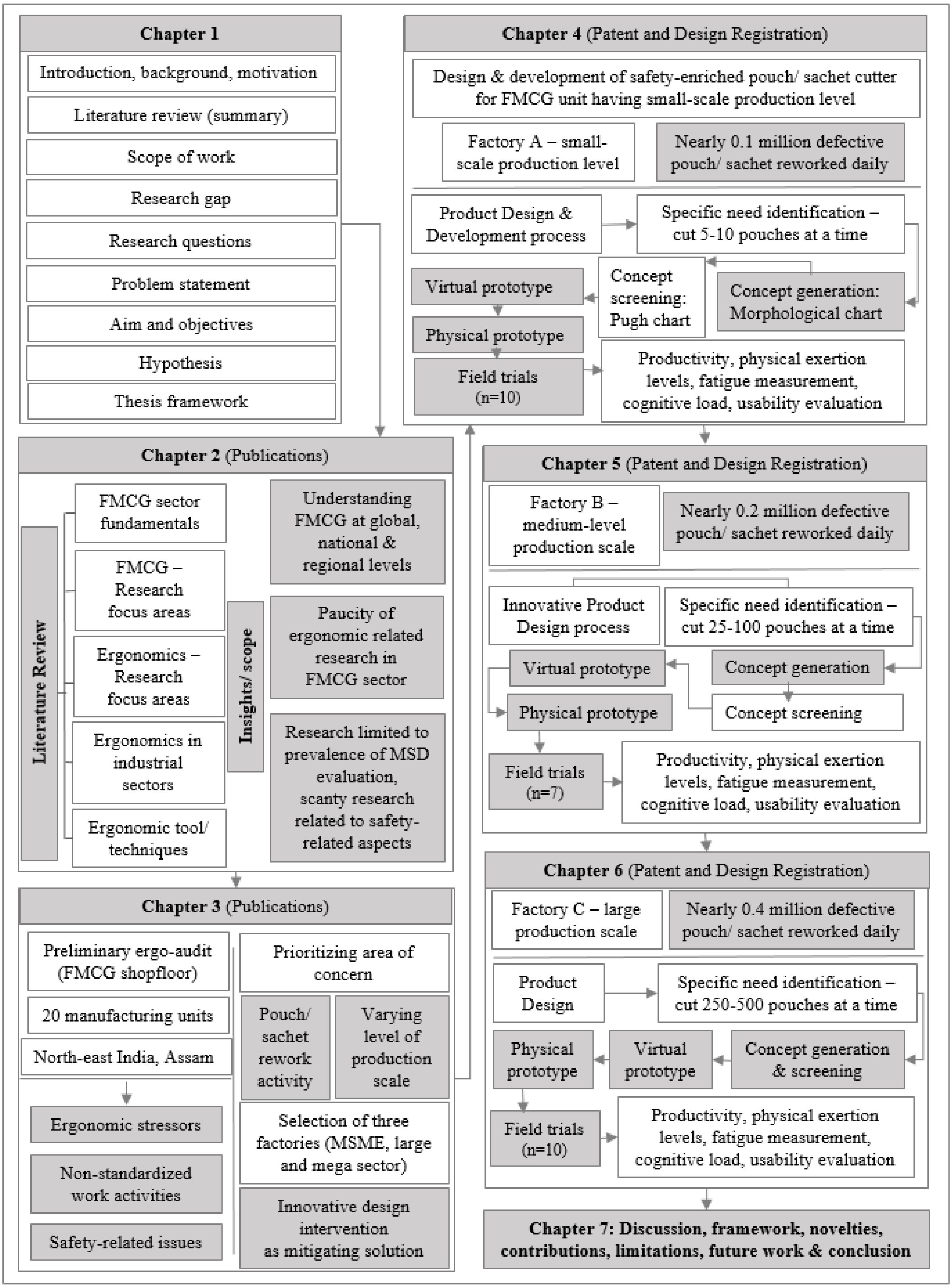


Figure 1.2: Thesis workflow and content of various chapters. (Source: author)

Table 1. 1: Research questions and objectives organized in various chapters and associated scholarly outcomes. (Source: author)

Chapter	Research Question	Objectives	Publications/ Patents/ Design Registrations
2	**R.Q. 1:** What are the current trends of ergonomic-related research and its corresponding ergo tools/ techniques used in diverse Industrial setups?	**Objective 1**: To understand the state-of-the-art literature on ergonomic issues and the implementation of ergonomic interventions in diverse industrial sectors.	Singh, Gurdeep & Karmakar, Sougata (2021). Scope of improvement in assembly line of FMCG industries through ergonomic design. *In: Design for Tomorrow – Volume 3, ICoRD'21*. https://doi.org/10.1007/978-981-16-0084-5_16 **[Scopus] [Springer]** Singh, Gurdeep & Karmakar, Sougata (2023). Identification of appropriate tools and techniques for ergonomic evaluation in FMCG industrial shopfloor. *In: Design in the era of industry 4.0, Volume 1, ICoRD'23*. https://doi.org/10.1007/978-981-99-0293-4_9 **[Scopus] [Springer]**
3	**R.Q. 2:** What are the various OSH-related issues prevailing at manual/ semi-automated Indian FMCG manufacturing units? **R.Q. 3:** Which area of concern from OSH purview must be prioritized according to the shopfloor workers, manager/ supervisors, and factory management?	**Objective 2**: To study the OSH-related issues in the Indian FMCG shopfloor **Objective 3:** To identify the most critical areas of concern in the context of work/ worker safety	Singh, Gurdeep & Karmakar, Sougata (2022). Preliminary survey in FMCG shopfloors to understand operational activities for identifying ergonomic stressors: A case study from North-east India. *In: Ergonomics for design and innovation, HWWE 2021. Lecture Notes in Networks and Systems, Volume 391*. https://doi.org/10.1007/978-3-030-94277-9_9 **[Scopus] [Springer]** Singh, Gurdeep & Karmakar, Sougata (2024). Innovative hand-tool design for cleaning of slippery floor and broken glass pieces in shopfloor of FMCG sector. *In: Innovative design for societal needs, NERC 2022*. https://doi.org/10.1007/978-981-99-6468-0_1 **[Springer]**
4, 5 & 6	**R.Q. 4:** What are the various criteria or considerations to be taken care of for addressing the identified OSH-related issues in the FMCG shopfloor? **R.Q. 5:** What could be the most feasible solution to address identified OSH-	**Objective 4:** To design and develop innovative context-specific ergonomic design interventions as a mitigating solution.	Hand-held apparatus for extracting contents of sachet /pouch. **[U.S. Patent, Granted]** **U.S. Patent Number:** 11319103 https://patentcenter.uspto.gov/applications/17092144

4, 5 & 6	related issues in the FMCG shopfloor from the ergonomics perspective? **R.Q. 6:** Will the same solution be applicable/ implementable for different scales of production/ production levels in the FMCG production process? **R.Q. 7:** How can the implemented solution be tested/ justified?	**Objective 5:** To evaluate the efficacy of the developed innovative design interventions.	Design of safety-enriched sitting-position oriented hand-held apparatus for damaged pouch and sachet cutting for rework in FMCG industries. **[Indian Patent, Granted]** Patent Number: 355504 Design of safety-enriched standing-position-oriented mechanized apparatus for damaged pouch and sachet cutting for rework in FMCG industries. [**Indian Patent, Granted]** Patent Number: 364959 Pouch/ sachet cutting and squeezing apparatus. **[Indian Patent, Granted]** Patent Number: 415999 Ergonomic Sachet Cutting Apparatus for FMCG Rework. **[Indian Design, Granted]** Design Registration Number: 329290-001, Class: 08-03 Cutting and Squeezing Apparatus for Defective Pouch/ Sachet Rework. **[Indian Design, Granted]** Design Registration Number: 360578-001, Class: 08-03 Mechanized Pouch Cutter for FMCG Rework. **[Indian Design, Granted]** Design Registration Number: 329288-001, Class: 08-03 Singh, G. & Karmakar, S. (2024). Addressing OSH challenges in non-standardized work practices in small-scale FMCG units by introducing context-specific ergonomic apparatus. *WORK: A Journal of Prevention, Assessment & Rehabilitation review.* https://doi.org/10.3233/WOR-240096 **[SCIE] [SAGE PRESS]**
7	**R.Q. 8:** What should be the actionable framework to address OSH-related issues for factory shopfloors with different scales of production?	**Objective 6:** To propose a framework for developing safety-related design interventions for the factory shopfloor.	Yet to be Published.

1.11 Outlines of the Thesis

The present research study has been divided into seven chapters. A summary of each chapter is discussed below:

Chapter 1: This chapter focuses on the present research study's introduction, background, and urge/ need. The summary of current research pertaining to the research topic is discussed, along with the research gap and associated research questions. The aim, objectives, and hypothesis of the current study are highlighted in this chapter. A summary of research outputs (scholarly) and the organization of the thesis is discussed in the latter half of this chapter.

Chapter 2**:** This chapter explores the scope of probable interventions (from the OSH perspective) that may be incorporated to improve the working conditions within the work domain chosen for the current research study, i.e., FMCG industries. In this chapter, a thorough literature review is carried out to get familiar with the current research trends in the work domain, the scope of improvement areas, tools and techniques being considered by other researchers, work parameters involved in the domain-specific work, and the corresponding tools which may be best suited to steer the study ahead.

Chapter 3**:** This chapter focuses on the methodology adopted and subsequent insights gathered from conducting rigorous preliminary ergo-audit at FMCG manufacturing units to get acquainted with the current issues and challenges faced by the various stakeholders (workers, safety managers, production managers, factory management, etc.). Once several issues and challenges are identified, the most critical area of concern is prioritized. Afterward, the work (practice-based/ practical work) commences to provide mitigating solutions for the improvement of the existing scenario. Three different levels of industries (with varying levels of production scale, employee engagement, etc.) are selected (Factory A, B, and C), and probable innovative mitigating solutions for them are planned.

Chapter 4**:** This chapter discusses in detail the design and development process of the innovative design intervention developed as a mitigating solution for Factory A (a factory with a small-scale production level). The design and development process, ranging from the pre-conceptual phase to the field trial phase, is discussed in detail. The innovative product developed is based on the thorough implementation of ergonomics and design principles.

Chapter 5: The design and development process of the innovative design intervention developed as a mitigating solution for Factory B (a factory with a medium-scale production level) is illustrated in Chapter 5.

Chapter 6**:** This chapter provides insights into the design and development process of the innovative design intervention developed as a mitigating solution for Factory C (a factory with a large-scale production level).

Chapter 7**:** This chapter elucidates the overall contributions and importance of the research carried out. The key insights fetched from the study, actionable framework, the research's novelties, and contributions to the various avenues (knowledge base, industry, society, etc.) have been discussed. Limitations and future scope of work, along with the conclusion, are also highlighted in this chapter.

2

Scope of Ergonomic Interventions in Workplace of FMCG Industries and their Corresponding Tools/ Techniques for Ergo-evaluation

Abstract

The FMCG industry is a prominent industry worldwide that impacts the life of every individual across the globe daily. An extensive literature review was carried out to gain in-depth familiarity with the FMCG background, current scenario, future perspectives, and major research trends in this domain. This revealed that this industry has vast potential and bright perspectives worldwide, especially in India, wherein, through government support, it is rapidly growing in northeastern states. Plenty of research is being carried out in the FMCG domain; however, the major focus of such research is achieving production/ operation excellence. Scanty research has been carried out in this domain from an ergonomics perspective, and very little is known about the OSH scenario of FMCG shopfloors. Literature regarding ergonomics-related research in the varied industrial sectors was also explored. It revealed that plenty of research has been carried out to determine the prevalence of ergonomic stressors and MSDs on the industrial shopfloor, and preventive measures in the form of guidelines, physical exercise, therapy, rehabilitation measures, etc., have been proposed. However, there lies the paucity of practical interventions as mitigating solutions. Several ergonomic tools/ techniques were also explored that may be further used for potential ergo-evaluation on the FMCG shopfloor.

2.1 Introduction

As the intended topic of research is related to ergonomic interventions for the improvement of shopfloor working conditions of Indian FMCG industries, especially addressing safety-related issues from an ergonomics perspective, an exhaustive literature review was carried out using online search engines like EBSCOhost, Web of Science, Scopus, Google Scholar, and Shodhganga. In addition to online search, printed books, government reports, and journals were also searched in the Laxminath Bezbaroa Central Library, Indian Institute of Technology (IIT) Guwahati. The primary keywords used for the online search were ergonomics, workstation design, work measurement, musculoskeletal disorders, occupational health and safety, FMCG, manufacturing, make and pack production, productivity, assembly line, paced assembly, lean manufacturing, design interventions, Indian manufacturing industry, manufacturing in developing nations, Innovation, Industry 4.0, accident and injuries at workplace, etc. Further combinations of these keywords were also used to extract other research articles. This literature was carried out with the purpose of:

- To gain background on the research topic.
- To know the state-of-art status of the ongoing research in the selected domain.
- To identify the concepts relating to it, potential relationships between them, research design, methodology, and techniques used by other researchers to carry out their research in the selected domain.
- To identify the gap in earlier studies and further formulate research questions, aims, objectives, and researchable hypotheses.

A large plethora of literature exists in the domain of ergonomics, and it encompasses vast fields and areas of human society, viz. agriculture, healthcare, manufacturing industries, fashion technology, aviation, military establishments, etc. However, the current literature review only focuses on ergonomics-related research in manufacturing and industries. A brief review of the literature concerning ergonomics and implementation in diverse industrial sectors and FMCG is compiled in the following sub-sections. Foremost, the literature pertaining to FMCG is presented to clearly understand the domain and background of the current research.

2.2 FMCG: Background

FMCGs are low-priced items used with a single or limited number of consumption occasions (Baron et al., 1991) and are sometimes referred to as consumer packaged goods or groceries.

FMCG comprises three major product segments: food, beverage, and household (Key Note, 2006; IBEF, 2024). FMCG is an essential part of day to day life of every person across the globe and accounts for more than half of all consumer spending (Kiran Sable, 2019; Dinesh et al., 2023; IBEF, 2024). It comprises products such as food & beverages, over-the-counter drugs, health care products, and other products such as personal care, toiletries, and home care products. In the present highly competitive and dynamic global market, the global FMCG market has witnessed significant growth owing to lifestyle changes, demographic variations, an upsurge in organized retail, a rise in disposable income, and an increase in urbanization (ASSOCHAM, 2023).

In the current scenario, growing at much faster rates and providing employment opportunities to massive workforces among all the nations of the world, the global FMCG market is projected to reach 15,361.8 billion USD by 2025, registering a CAGR of 5.4% from 2018 to 2025 (Kiran Sable, 2019; Delikurt and Corum, 2022). This indicates the importance of the FMCG market globally and predicts its future trend, which seems to be very bright across the global arena. Business analysis firms & business consultants are the significant sources of predicting and reviewing the market analysis and trends of FMCG, and very little has been contributed by the academicians in this context (Grunert et al., 1997; Francis et al., 2006). The global FMCG market can be segmented into three broad categories based on product type, distribution channel, and region.

❖ ***Based on product type:***

- Food and beverages
- Personal care (skincare, cosmetics, hair care, others)
- Healthcare (over-the-counter drugs, vitamins & dietary supplements, oral care, feminine care, others)
- Home care

❖ ***Based on distribution channels:***

- Supermarkets
- Hypermarkets
- Grocery stores
- Specialty stores
- E-commerce and others

❖ ***Based on geographical regions:***

- North America
- The U.S.
- U.K.
- Rest of Europe
- Asia-Pacific
- UAE
- India

The prominent players across the global FMCG market are Nestle, Procter And Gamble, Unilever Group, The Coca-Cola Company, Pepsico Co. Inc., Kimberly-Clark Corporation, Dr. Pepper Snapple Group, Inc., Revlon, Inc., Johnson & Johnson, and steeply rising Indian FMCG player Patanjali Ayurved Ltd. In 2018, Nestle, Procter & Gamble, and Pepsico remained the world's largest fast-moving consumer goods companies in the world (Kiran Sable, 2019; Neena Prasad, 2019; CMIE, 2020; ASSOCHAM, 2023; Dinesh et al., 2023; IBEF, 2024).

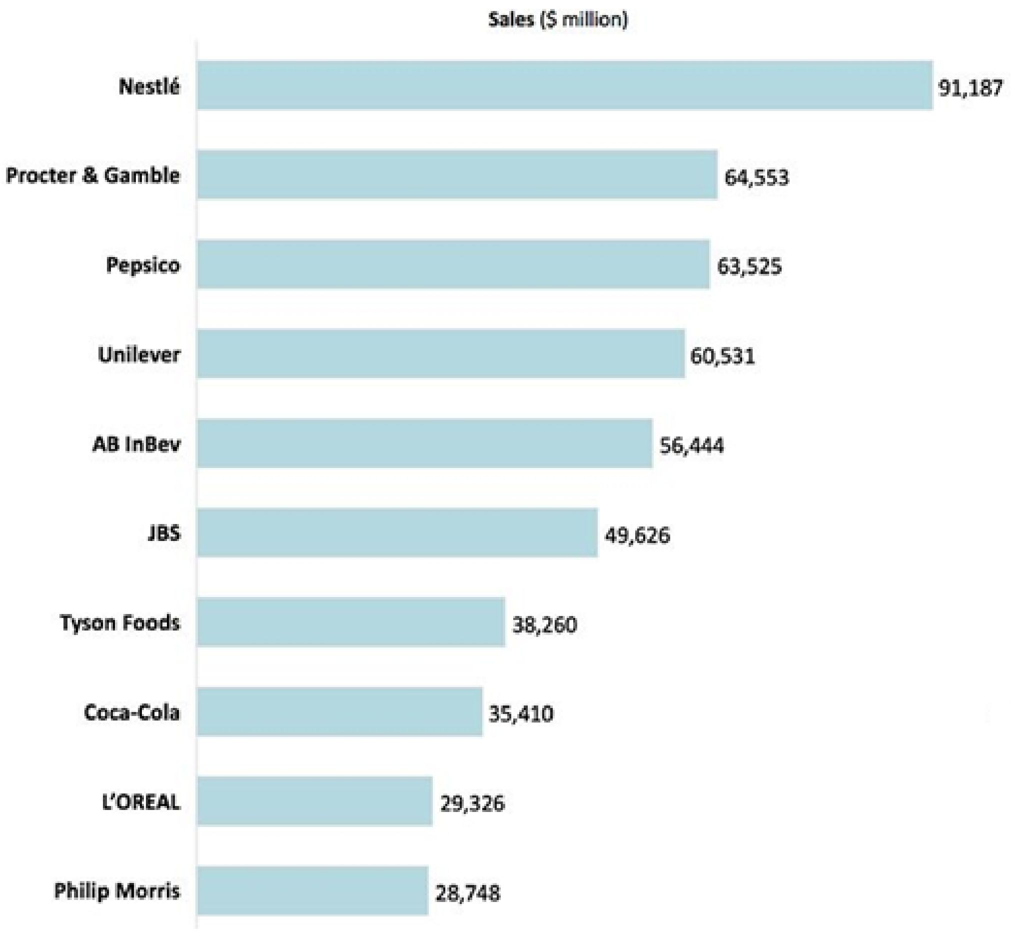


Figure 2.1: Top 10 largest FMCG in the world in the year 2018 (Source: Consultancy. uk, 2018)

These FMCG giants have a worldwide presence and are expanding their businesses and manufacturing facilities in Asia-Pacific, especially in India, due to liberal government policies and the availability of cheap labor and raw materials. Almost every Indian is familiar with these names and has consumed their products daily. So, these are not aliens to the Indian Economy. The top 10 FMCG players of 2018 across the globe are listed in Figure 2.1. The global FMCG industry, which includes household and personal care products and processed foods and beverages, is one of the most important industrial sectors worldwide and is witnessing upward trends. The FMCG industry's current and future trends (2018-2025) are discussed and analyzed in subsequent paragraphs for all three classification categories.

Product Type:

Figure 2.2 indicates that in 2018, the food & beverage segment held the majority share in the global FMCG market, and it is expected to hold a significant share in the global market throughout the forecasted period (2018-25). The food and beverage segment had witnessed major investments in its production processes as fixed capital investments, thus highly automated. Other FMCG segments, like personal and home care, are less capital-intensive than the food and beverage segment. These are working with the semi-automated production process and are labor-intensive. Apart from the food and beverage segment, the other FMCG segments are also forecasted to grow steadily, as were growing recently.

Figure 2.2: FMCG product type comparison (2018-25). (Source: Kiran Sable, 2019)

Distribution Channels:

Compared to other distribution channels, the global FMCG market in 2018 was dominated by the supermarkets and hypermarkets distribution channel segment (Figure 2.3). It happened because of the rise in disposable income, which further increased demand for a one-stop solution for all shopping needs (Kiran Sable, 2019; Dekimpe and van Heerde, 2023). Other distribution channels witnessed steady growth and are expected to continue the same trends in the future, too. With the growing e-literacy and smartphone usage in developing nations, E-commerce may pick up soon compared to other segments. According to Nielsen, E-commerce contributed 0.4 percent to FMCG sales in 2016, and in 2018, it is expected to be around 1.3 percent of the branded packaged FMCG sales globally, and it is expected to contribute 11% of global FMCG sales by 2030. Especially in India, the contribution of the e-commerce channel to FMCG sales now stands at over 1 percent and has grown by over 101 percent since last year (Nielsen, 2018).

Figure 2.3: FMCG distribution channel type comparison (2018-25). (Source: Kiran Sable, 2019)

Geographical Region:

North American, Latin American, and European FMCG markets are expected to remain dominant and grow steadily in the FMCG market in the current regime and beyond. However, Asia-Pacific is expected to grow at the highest CAGR of 8.0% owing to changes in the lifestyles of the people in these countries, which is led by globalization and an increase in the working population (Kiran Sable, 2019; IMF, 2023) (Figure 2.4).

Figure 2.4: FMCG market's global presence comparison. (Source: Kiran Sable, 2019)

Especially in Asia, the rise in the affluent population and increased penetration of the internet and social media among the youth and adults has increased the consumption of FMCG products, which makes way for the growth of the FMCG market in the region (WEF, 2019; IBEF, 2024). The climate of Asia-Pacific countries is highly suitable for producing large raw material bases for many FMCG companies. Besides the availability of raw materials, low labor cost is another driver of the growth of the FMCG industry in these countries. Low labor costs support the low production cost, making these countries favorable investment destinations for the FMCG industry (World Bank, 2023).

Indian FMCG industries have higher growth potential than the world due to an increase in the purchasing power of the Indian population and its sizeable youth population coupled with the growth stage of the industries (ICICI Lombard, 2022; IBEF, 2024). In India, there has been an increase in disposable incomes both in the urban cities and in rural India. The share of spending on necessities, leisure & recreation, and miscellaneous goods & services has increased with the rise in household incomes and disposable incomes. In addition, the government's liberal policies to promote FMCG (Debnath and Roy, 2021; Gunasheela, 2021; IBEF, 2024), such as

- the provision (allowable limit) of 100 percent Foreign Direct Investment (FDI) in food processing and single-brand retail and 51 percent in multi-brand retail and other
- introduction of a consumer protection bill with special emphasis on setting up an extensive mechanism to ensure simple, speedy, accessible, affordable, and timely delivery of justice to consumers

- liberal Goods and Services Tax (GST) policies for the FMCG industry (as many of the FMCG products such as soap, toothpaste, and hair oil now come under the 18 percent tax bracket against the previous 23-24 percent rate)

All these have paved the way for multinational brands to extend their manufacturing capabilities further in India. Many foreign FMCG players are expanding into new geographies and categories for their manufacturing and retail capabilities, especially in tier II and III cities, which now witness faster growth in modern trade (Statista, 2024). Per the central government's FDI norms, the minimum capitalization for foreign companies to invest in India is 100 million USD. Between April 2000 and June 2022, the FMCG sector witnessed an FDI inflow of 20.84 billion USD (IBEF, 2023). Major FMCG players like Nestle, Pepsico, Unilever, Procter & Gamble, etc., have expanded their manufacturing units in India through their Indian subsidiaries to leverage the cost arbitrage opportunities with the West. They have started manufacturing their FMCG products in India at more competitive rates while maintaining their high quality and cost efficiency and exporting them to developed nations like Australia, Japan, and the U.K. to earn significant profits (Jayanthi R., 2017; ICICI Lombard, 2022; IBEF, 2024).

With these data and figures, one can understand the importance of the global FMCG market and its ever-increasing roles in the lives of every human residing in every nook and corner of the world. Further, it is prominent that its growth potential in the Indian sector is very high and must be carefully understood from every aspect, whether retail, manufacturing, logistics, etc., to reap its maximum benefits and boost the Indian economy.

2.2.1 FMCG industry in India

The FMCG sector is an important contributor to India's GDP growth. Currently, the FMCG industry is the fourth largest sector in the Indian economy and employs around 3 million people, accounting for approximately five percent of the total factory employment in India (Neena Prasad, 2019; CMIE, 2020; IBEF, 2023; ASSOCHAM, 2023). The FMCG sector has proliferated from 31.6 billion USD in 2011 to 52.75 billion USD in 2018 (Kudal and Dawar, 2020). As per IBEF's January 2019 FMCG market report, the FMCG sector was expected to grow at a CAGR of 27.86 percent and reach 103.7 billion USD by 2020. Unfortunately, along with the other industrial sectors, the FMCG sector was also hit by the Coronavirus Disease 2019 (COVID-19) pandemic, and the nationwide lockdown was imposed in the first and second quarters of the financial year 2020-21. In the post-COVID scenario, when the restrictions were over, the FMCG sector did well, and the FMCG market reached USD 56.8 billion in December

2022 (Unicommerce, 2023). The total revenue of the FMCG market is now projected to grow at a CAGR of 27.9% from 2021 to 2027, reaching nearly USD 615.87 billion (IBEF, 2023). The Indian FMCG sector remains competitive due to the presence of multinational companies, domestic companies, and unorganized sectors (Aparna, 2018). By adopting various strategies to stay competitive, FMCG companies tend to increase revenues and expand their customer base year after year (Jayanthi R., 2017), influencing every citizen daily.

2.2.2 FMCG segments and present scenario

Indian FMCG sector has three main segments – food and beverages, which account for 19 percent of the industry; healthcare, which accounts for 31 percent; and household and personal care, which accounts for the remaining 50 percent (Care Rating, 2018). In contrast to the global FMCG sector, which has the food & beverage segment as the majority shareholder, the Indian FMCG sector has personal care products as the major shareholder. The typical structure of the Indian FMCG sector is depicted in the following Figure 2.5.

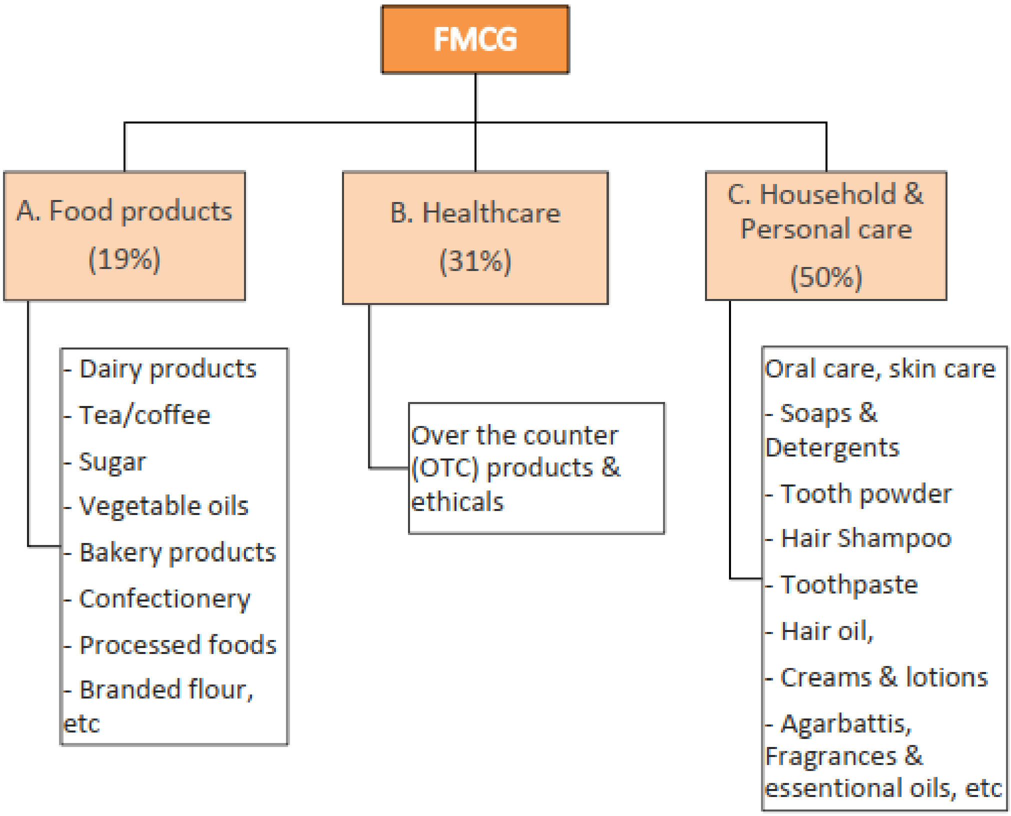


Figure 2.5: Indian FMCG market (product share). (Source: Care Rating, 2018)

In the Indian scenario, most FMCG players compete in similar personal care products like hair oil, shampoos, fairness creams, cosmetic products, etc. These traditional Indian FMCG players are compelled to cut costs within their production and marketing structures to sustain the prevailing cut-throat competition and remain competitive with multinational giants now investing in India through their Indian subsidiaries (Vethirajan, 2014). The Indian FMCG industry is thus highly competitive due to the presence of multinational, domestic, and unorganized sectors (Aparna, 2018). By adopting various strategies to remain competitive, FMCG companies tend to increase revenues and expand their customer base. There are several key differences among the existing Indian FMCG players. Multinational companies and their subsidiaries have huge capital with them to invest in fixed capital assets (plant, machinery, infrastructure). They are thus investing in mega projects at well-desired places based on their own facility layout and planning and company policy plans.

On the other hand, typical Indian FMCG companies are looking for government support through capital rebates, tax exemptions, and infrastructure establishment (industrial plots and parks) due to their limited financial and budgetary constraints. In such conditions, their production, distribution, and exchange systems and concepts of property ownership are often radically different (Vethirajan, 2014). Table 2.1 illustrates the top ten Indian FMCG companies in various classification categories.

Table 2.1: Top 10 Indian FMCG companies. (Source: Jayanthi R., 2017)

Rank	As per a higher consumption rate	As per Revenue	Providing every house hold with exactly the product India wants	According to the brand value and revenue earnings	By Revenue & Income	Providing different products for the use of the customer
1	Hindustan Unilever Limited	Hindustan Unilever Limited	Hindustan Unilever Limited	Hindustan Unilever Limited	ITC Limited	Hindustan Unilever Limited
2	ITC Limited	Patanjali Ayurved	Colgate-Palmolive	Colgate-Palmolive	Hindustan Unilever Limited	ITC Limited
3	Dabur India Ltd.	ITC Limited	ITC Limited	ITC Limited	Britannia Industries Limited	Amul
4	Britannia Industries	Nestle India	Nestle India	Nestle India	Nestle India	Dabur India Ltd.

5	Godrej Group	Godrej Group	Parle Agro	Parle Agro	Dabur India Ltd.	Britannia Industries Limited
6	Parle Agro	Britannia Industries Limited	Britannia Industries Limited	Britannia Industries Limited	Marico Limited	Marico Limited
7	Amul	Dabur India Ltd.	Marico Limited	Marico Limited	Patanjali Ayurved	Pidilite Industries
8	Pidilite Industries	Tata Global Beverages	Procter & Gamble	Procter & Gamble	Godrej Group	Godrej Group
9	Patanjali Ayurved	Marico Limited	Godrej Group	Godrej Group	Glaxo SmithKline	Parle Agro
10	Haldiram's	Colgate-Palmolive	Amul	Amul	Colgate-Palmolive	Colgate-Palmolive

Multinational FMCG groups are capital-intensive, have superior manufacturing units spread across several acres of land, and have fully automated facilities. Their production capacities are very high compared to typical Indian FMCG groups. They hold an edge over their Indian counterparts in terms of superior technology combined with a steady flow of capital, while domestic companies compete based on their well-acknowledged brands, an extensive distribution network, and an insight into local market conditions (Vethirajan, 2014; Sangeetha, 2017). However, such huge investments (64%) have been witnessed in the food processing segment only (Figure 2.6), as major multinational FMCG groups are focussed on reaping the benefits of a large raw material base available in India for their products. The other FMCG segments, particularly personal care goods manufacturing, tend to work under large and MSME sectors. They resort to labor-intensive and semi-automated production processes and often engage in casual/ contractual labor for non-standardized work activities, especially packing and reworking goods (Singh and Karmakar, 2022).

The following figure, Figure 2.6, reveals the FDI inflows into the overall Indian FMCG market from 2000 to 2017. It is evident from Figure 2.6 that the personal care goods manufacturing (soap, cosmetics, hair oil, toiletries, etc.) received only marginal FDI inflows (10 percent) as compared to the food processing segment that received the major share (64 percent). As such, most Indian FMCG manufacturing units manufacturing personal care products lie in the large and MSME sectors and rely on semi-automatic production processes.

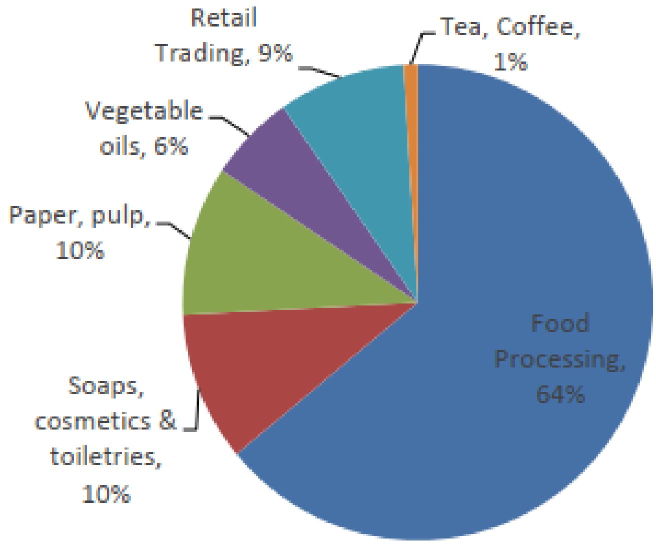


Figure 2.6: FDI inflow into the Indian FMCG market (April 2000 – December 2017)
(Source: Care Rating, 2018)

Table 2.2: Overview of the global FMCG industry. (Source: Singh and Karmakar, 2023)

National Category	Product Segment Ranking	Production Setup	Manual Labor Engagement
Developed Nations	1. Food & beverages	Highly automated	Limited engagement
	2. Household & personal care products	Highly automated	Limited engagement
	3. Health care products	Highly automated	Limited engagement
Developing Nations	1. Household & personal care products	Semi-automated	Highly labor intensive (packaging activities)
	2. Health care products	Semi-automated	Medium labor intensive
	3. Food & beverages	Highly automated	Low labor intensive

Table 2.2 above depicts an overview of the FMCG sector worldwide in the context of production setup and labor engagements. It reveals that FMCG manufacturing of household and personal care products relies on semi-automatic production and remains highly labor intensive, especially engaging manual labor in its widespread packing activities. The Indian manufacturing industry

has a mix of all types of industrial setups based on capital and labor employment (IIP, 2014) and can be classified into three major categories:

- Micro, Small, and Medium Enterprises (MSMEs) having investments in plant and machinery up to 2.5 million, 5.0 million, and 10 million, respectively
- Large units having investment in plant and machinery above 10 million
- Mega Project having investment in fixed capital investment above 1 billion or generating a minimum of 1000 regular employment

Indian FMCG companies manufacturing personal care goods, viz. hair oil, shampoo, soap, etc., have the characteristics of typical Indian manufacturing units (semi-automatic production setup, labor-intensive, drudgery, etc.). Although being in an organized sector, they are bound to have all the characteristics of MSMEs. They seek government support to establish their manufacturing and production facilities and thus adhere to government policies to extract the benefits offered by various government organizations on the national or regional level. In the recent past, government policies like 'Make in India' and North-East Industrial and Industrial Promotion Policy (NEIPP) have helped several sectors to boost their growth in potential geographical regions across India, especially in the northeastern areas and hilly regions of Himachal and Jammu Kashmir. Several capital rebates, tax exemptions, and manufacturing plots (industrial parks) have been provided to entrepreneurs/ business houses to invest in these states to set up their industries and expand the existing ones (NEIPP, 2007; IIP, 2014). Assam has thus witnessed the growth of Indian FMCG units competing in personal care products (hair oil, shampoo, cosmetics) in the past few years as compared to other northeastern states (NEIDS, 2017; IIP, 2019). From the above discussion, it's pretty evident that the FMCG sector is the fastest growing sector in the Indian economy, having characteristics of both the large industry (multinational groups/ capital intensive / higher production capacities) and the MSMEs (Indian business groups/ labor intensive / capital constrained/ lower production capacities); such medium enterprises are being supported by the various government policies from time to time.

2.2.3 Expected growth of the FMCG sector in India

2.2.3.1 COVID-19 disruption: effects on Indian FMCG sector

With the advent of COVID-19, from mid-March 2020 onwards, a gradual disruption in the supply chain was witnessed. Due to the nationwide lockdown, operations at multiple manufacturing units, warehouses, and office locations were temporarily shut or scaled down or were operating as per local guidelines. As a result, in the fourth quarter of the Financial Year (F.Y.) 2019-20, the FMCG sector grew at a slow rate of 6.3% (including e-commerce) in value terms, which was a sharp downward trend compared to its 13.8% growth, that the sector reported in the same period in 2018-19 (Shetty et al., 2020; Tandon, 2020). Interestingly, the demand for the packaged food segment of FMCG grew by 7.8% in the March quarter of 2020, compared to non–food categories, which grew by only 1.8% in value. This resulted from panic buying and stockpiling of the food items that occurred in the Indian market at the end of the March quarter as the country prepared for the lockdown. Despite the panic buying and stockpiling trend at the end of the March quarter in the FMCG sector, 2020 and 2021 were gloomy years for the sector.

Further, as expected, the demand for certain products from the 'household and personal care category,' like body showers, moisturizers, face wash, hair gel, hair oil, etc., witnessed a continuous downturn and didn't recover until Q4-FY 2020-21. This is because these products are discretionary, and consumers tend to delay their purchases when there are fears of job losses and falling disposable incomes (Care Rating, 2020). Despite the slowdown in the unprecedented times of COVID-19, the FMCG sector's long-run outlook remained positive, and consumer spending was predicted to accelerate, supported by favorable dynamics in the country such as rising young population, increasing affluence, increasing digital connectivity and distribution, young population entering the workforce, growth in nuclear families, etc.

2.2.3.2 Growth prospects – F.Y. 2023 - 2024 and beyond

As the situation improved and the complete COVID-19 restrictions were lifted on 15th March 2022, the FMCG sector flourished again. At this juncture, the market researcher NielsenIQ estimated 7-9% growth in India's FMCG market in 2023, with inflationary pressures easing and the rural markets displaying early signs of growth in the first quarter (Tandon, 2023). According to the IBEF Report, 2023, the Indian rural FMCG market is estimated to reach a valuation of USD 220 billion by 2025, and rural India accounts for more than 40% of consumption in major FMCG categories such as personal care, fabric care, and hot beverages. Every rating and financial strategy analyzing agencies in such situations speculates that the Indian FMCG industry (depending upon future consumption growth within the country) can generate an additional 3-4 million employment opportunities (ICICI Lombard, 2022; IMF 2023; IBEF, 2024; Statista, 2024).

2.2.4 Scope of the FMCG sector in Assam, India

Recently, government policies like Make in India, IIP, and NEIPP have helped several sectors boost their growth in potential geographical regions across India, especially in the northeastern areas and hilly regions of Himachal and Jammu Kashmir. Several capital rebates, tax exemptions, and manufacturing plots (industrial parks) have been provided to entrepreneurs/ business houses to invest in these states to set up their industries and expand the existing ones. Assam has witnessed the higher growth of Indian FMCG units competing in personal care products (hair oil, shampoo, cosmetics, etc.) in the past few years as compared to other northeastern states.

Further, Assam's Industrial and Investment Policy (2014) promoted the growth of Small and Medium Enterprises (SMEs) and FMCGs in Assam. Several Industrial parks were established throughout Assam to allocate space to these investors and entrepreneurs. Export Promotion Industrial Park (EPIP), Brahmaputra Industrial Park (BIP), Tea Park, Biotech Park in Guwahati, and Industrial Growth Centres in Sonitpur and Goalpara were established to provide manufacturing sheds/ units for such SME and FMCG units, primarily with the vision to provide employment opportunities to the people of Assam as such units being labor-intensive.

To fulfill this mandate, NEIPP and the Industrial and Investment Policy of Assam (2014) levy one major restriction on the business groups availing plots and sheds in such parks, - a unit shall have employment of a minimum of 80% people of Assam in the managerial cadre, and a minimum of 90% people of Assam in the non-managerial cadre (NEIPP, 2007; IIP, 2014). Adhering to these obligations, mega, large, medium, and small FMCG groups established in Assam are employing a large number of the Assamese population working in their semi-automated plants. Most of these business groups had manufacturing plants in other states of India and were thus employing their native people. These recently established FMCG manufacturing units in Assam currently employ more than 0.15 million skilled/ unskilled native workforce of Assam. At present, the FMCGs are major employment providers to the people of Assam and thus become an important sector for society at large. Table 2.3 elucidates a few major investments done in Assam by the industrialists/ business houses after May 2016.

Table 2.3: Major investments in Assam (after May 2016)
(Source: Industries & Commerce Department, Assam Government)

Name of Unit	Address	Finished Goods	Employment	Type of Project	Investment (Crores)
Patanjali Ayurved Ltd.	Sonitpur, Tezpur	Ayurvedic and herbal products	4650	Mega	1,339.76
Dabur India	Sonitpur, Tezpur	Ayurvedic and herbal products	1075	Mega	353.22
Emami Ltd.	Kamrup	Cosmetic products, Hair oil	1000	Mega	300.00
M/s Britannia Industries	Tezpur	Biscuits and Bakery	710	Mega	168.50
Ajanta Pharma Ltd.	Kokrajhar	Over-the-counter drugs, pharmaceutical	132	Mega	155.58
ITC Ltd.	Bortezpur	Soap, Biscuits	388	Mega	177.19
Marico Ltd.	Kamrup	Hair oil	375	Large	17.10
Cavin Kare Pvt. Ltd.	Matia	Shampoo, Hair color, Oil, cosmetics	150	Large	40.00
M/s Alliance India	Kamalpur	Soap, Talc powder	160	Large	33.17
VLCC Personal Care Ltd.	Goalpara	Face creams, Hair oil	31	Large	16.00
Dharampal Premchand Ltd.	Kamrup	Homecare products	70	Large	10.86
Northern Aromatics Ltd.	Balipara	Essential oils and Herbal products	32	SME	9.98
ACME Industries	Kamrup	Toothpaste	260	SME	8.50
Bajaj Corp. Ltd.	Kamrup	Hair oil	172	SME	5.41
Darshan International Ltd.	Kamrup	Incense sticks	140	SME	4.02
APY Pharma Ltd.	Kamrup	Essential oil & pharmaceutical formulations	10	SME	3.90

2.2.5 Scope and necessity of applied ergonomics in the FMCG industry

In the recent past, many Indian businesses have expanded their manufacturing units in Assam to reap the benefits provided by NEIPP and IIP Assam. The machinery installed in these newly built plants has been procured from their major Original Equipment Manufacturers (OEM), which provided them with the machinery in other states, especially in North India (PHD Chamber, 2017; Indiamart, 2018;). It may concern the productivity and occupational health of the Assamese population working on the shopfloor of such manufacturing units (owing to their varied anthropometric and biomechanical characteristics).

Moreover, to compete with global FMCG competitors, such units tend to produce as much as they can from the existing production capacities; hence, long working hours, higher utilization of machinery, and labor are the typical features of these manufacturing units (Vethirajan, 2014; Aparna, 2018). In such a scenario, thorough investigations must be carried out across shopfloors of Indian FMCGs dwelling in Assam to improve productivity, OSH, and well-being of the native Assamese population. These FMCG units in Assam thus require immediate research studies to look into their production processes, shopfloor activities, and safety and well-being issues from an ergonomic perspective.

2.2.6 FMCG product manufacturing: ergonomic challenges & need for ergonomic study

The FMCG business is considered the most definitive instance of low-margin and high-volume business, wherein large volumes of small products are mass-manufactured on high-paced assembly lines. Worldwide assembly line-related work is associated with a high prevalence of MSD and OSH-related issues as per reported studies from the industrial sector (Delleman et al., 2004; Colombini and Occhipinti, 2006; Shin and Park, 2019). These are produced in bulk on a daily basis using production strategies of mass production, waste elimination, and flexible manufacturing. These are generally produced in manufacturing units that differ on the economies of scale: mega-scale, large-scale, medium-scale, and small-scale.

Mega and large-scale units are usually automated and have advanced manufacturing techniques, better production facilities, and considerably high production capacities. These are highly complex, capital intensive, and engage a considerable number of employees (Singh and Karmakar, 2023). In contrast to these, medium and small-scale production units are labor intensive, have semi-automated production processes, and have lower production capacities as compared to mega and large-scale production levels, occurring due to man-machine incapability, poor co-ordination, non-standardized layouts of plants, and several other work-related issues (Vethirajan, 2014; Aparna, 2018, Sanjog et al., 2019). In the Indian scenario, ignorance towards ergonomics – the science of human-machine capability is prominent across all industries, which is quite evident in such cases. All these factors contribute to ergonomic hazards and further lead to OSH and safety-related issues. Ergonomic aspects are not given much thought at the time of commissioning and installing most production units (Sanjog et al., 2016; Olabode et al., 2017; Reiman et al., 2021). In the Indian scenario, ergonomics research is mainly dedicated to the durable goods manufacturing sector working in micro, small, and medium sectors, and various context-specific recommendations in the context of shopfloor layouts and design interventions for workstation design have been suggested (O'neill, 2000; Sain and Meena, 2016; Shukla et al., 2017; Sharma et al., 2022).

Research within the Indian FMCG sector mainly concentrates on management aspects, and it is tough to find any reported study from an ergonomics perspective in this domain. Ergonomic stressors related to paced assembly, spatial arrangements of workers across paced assembly lines, hazardous risk factors, and efficacy of work measurement tools have not been studied in the context of the FMCG industry (Singh and Karmakar, 2022). OSH scenarios have remained underreported in the context of FMCG as the industries refrain from reporting data on injuries and accidents occurring at their factory shopfloors for various reasons (Philipsen, 2009; Zwetsloot et al., 2013; Noman et al., 2021; Kyung et al., 2023).

These research lacunae in the context of FMCG shopfloor activities and existing OSH scenarios demand the immediate attention of researchers, OSH, and safety activists to improve the working conditions of shopfloors in Indian FMCG manufacturing industries. Foreseeing the tremendous growth of Indian FMCG working in fragments across mega, large, medium, and small scales across India, especially in the northeast, its high employment generation perspectives in the northeastern state of Assam, and its contribution to the GDP of India; it is right time to conduct investigations from an ergonomic perspective in the existing workplaces of these industries to deeply understand the prevailing OSH scenarios, safety-related issues, bottlenecks to productivity and attempting/ proposing the best possible mitigating solution to improve the existing shopfloor conditions overall aimed at enhancing worker safety and productivity.

2.3 Ongoing Research in the FMCG Sector – Focus Areas

A detailed literature review of the FMCG sector prevailing worldwide and its associated challenges has been presented in the previous subsections. This sub-section presents the major research being carried out within the FMCG sector worldwide. The following sub-section briefly discusses various research focus areas within which researchers throughout the globe are actively engaged in research pertaining to the FMCG sector.

2.3.1 Manufacturing aspects and production/ operation excellence

In the context of assembly line-related work, the researchers' most prominent work concerns Assembly Line Balancing (ALB) (Sivasankaran and Shahabudeen, 2014). Various approaches towards ALB have been implemented to simultaneously minimize both (cycle times and ergonomic risks) associated with assembly line workers. Paramount use of exoskeletons (Iranzo et al., 2020), rest allowance evaluations (Finco et al., 2020), multi-objective optimization algorithms (Dalle Mura and Dini, 2019), discrete event simulations (Dode et al., 2016), well-balanced work scheduling (Moussavi et al., 2019), etc. are among the various adopted methods for achieving success in ALB related issues varying upon U-shaped, L-shaped, S-shaped, and I-shaped assembly line flow. Such techniques are primarily focused on achieving production/ operation excellence, and context-specific ergonomic improvements remain secondary and do not provide much-needed support to engaged workers.

2.3.2 Implementation of lean manufacturing principles and work-standardization approaches

In addition to the ALB approaches, researchers have also focused on implementing lean manufacturing principles in assembly line work systems. They debated its pros and cons among various assembly line industrial work (Vahtera et al., 1997; Landsbergis et al., 1999). Several researchers have argued that implementing lean principles in manufacturing improves production efficiency by eliminating unnecessary steps, waste, and error and is beneficial for mass production. However, other researchers argued that lean manufacturing might improve efficiency, but it resulted in other detrimental effects on the operators and workers from an intensification of the work. These researchers remain concerned that working conditions in lean settings lead to adverse employee outcomes (Cullinane et al., 2014; Huo and Boxall, 2018). Another debate moves around the impact of the implementation of Total Quality Management (TQM), Just in Time (JIT), Inventory Control, Continuous Improvement (Kaizen and Six Sigma), and Work-Standardization. All these are the managerial philosophy-specific guiding principles and goals for enhancing productivity through continuous improvement and waste elimination (Shah and Ward, 2003; Kuhlang et al., 2011; Botti et al., 2017). However, less emphasis is given to redesigning assembly workplaces and redesigning production/ logistic processes to reduce inventory/ lead time using various methodical approaches connecting Value

Stream Mapping (VSM) and Methods-Time-Measurement (MTM). All these measures would ensure excellence in production/ operation in assembly line work.

2.3.3 Operations, packaging, and inventory management

Another major focus area in assembly line-related work focuses on other operational aspects related to packaging and inventory management issues. Scheduling production processes in assembly line-related works is a complex task. These are considered multiproduct-oriented industries and prone to frequent portfolio changes occurring with changes in season and consumer preferences, thus requiring higher flexibility (Yee and Shah, 1997). Such works also focus on research on Stock Keeping Units (SKU) to manage the large volume of packing material, work in progress, and finished goods on its production floor (Van Elzakker et al., 2014). Much research in the assembly line industry is focused on packaging and new product development. Packaging is a critical marketing tool and an integral part of the FMCG industry's products; it plays a vital role in consumers' product choices and perceptions and results in increased sales and volumes. FMCG industries use packaging to gain competitive advantage; thus, it is considered a tool to revitalize their mature products (Wansink and Huffman, 2001; Rundh, 2005). However, the micro-analysis of the packaging activities, such as individual carton/ case packaging being done manually, remains ignored in such industries, and production efficiency is hampered. In recent years, in the wake of a newly introduced concept in manufacturing, Industry 4.0, the FMCG sector laid significant focus on its numerous technologies and associated paradigms, including Radio Frequency Identification (RFID), especially in packaging, Enterprise Resource Planning (ERP), and Internet of Things (IoT) in SKU management and logistics, and social product development (Lu, 2017; Rauch et al., 2020).

2.3.4 Supply chain, logistics, and distribution

Assembly line-related production operations notably depend upon highly efficient supply chains, logistics, and distribution channels. In particular, FMCG products depend on highly efficient distribution channels; plenty of research is thus focused on supply chain and distribution-related areas. A thorough analysis of logistics component costs, the characteristics of the products being transported, and providing adequate training and development for people involved in distribution and logistics management are major focus areas of the research being carried out in this area. It helps in minimizing transportation costs while maintaining high service levels. The research focused on warehouse management is also carried out in parallel (Oke and Long, 2007).

2.3.5 Identification and evaluation of ergonomic stressors

Plenty of ergonomics research in assembly line work focused on identifying and evaluating risk factors associated with prevailing ergonomic stressors in the industrial workplace. In most industries across the globe, among the assembly line industrial workers, low back pain is the most common reason for days away from work (Nelson and Hughes, 2009). In the majority of the industrial places dependent upon assembly line work, repetitive manual labor is a risk factor associated with wrist and hand disorders, such as tendon-related disorders, Carpal Tunnel Syndrome (CTS), and cramping of the hand and forearm (Hansson et al., 2000; Bridger, 2017). Researchers have further reported that Work-related Upper Extremity (WRUE) symptoms can include pain, tenderness, swelling, numbness, and loss of function in the fingers, hands, forearms, shoulders, upper back, and neck (Feuerstein et al., 2004). Other researchers studied the risks associated with sedentary tasks and reported physical inactivity and sedentary behavior, which entail health risks. Physical inactivity, i.e., performing insufficient amounts of moderate-to-vigorous-intensity physical activity, leads to cardiovascular diseases, obesity, depression, type II diabetes, and sometimes cancer (Commissaris et al., 2016). Assessing the risks associated with prolonged standing, researchers pointed out that Plantar Fasciitis is a relatively common foot-related problem in the manufacturing sector (Werner, 2010). Such findings suggested several options for primary and secondary prevention strategies like shoe rotation and the use of shoe pad cushions to lower the risk of Plantar Fasciitis. Here, it is interesting to note that earlier researchers highlighted the prevalence of various ergonomic stressors and their ill effects on workers. They have given some recommendations to improve the existing situations but have not provided any design interventions as solutions. There lies a paucity of literature suggesting/ proposing/ providing design interventions as mitigation strategies to counter all WMSDs issues prevailing on shopfloors across various industrial sectors.

2.3.6 OSH aspects related to accidents/injuries

Research on OSH issues related to accidents/ injuries has received less attention in all industrial sectors, especially in assembly line activities. However, these activities remain prone to using sharp-edged tools, slippery floors, heavy manual load handling, and other horseplay activities. Considering a critical industrial work-related issue, i.e., industrial accidents, injury rate, and worker compensation, the industries do not reveal much information (Pransky et al., 1999; Philipsen, 2009; Zwetsloot et al., 2013; Noman et al., 2021; Kyung et al., 2023). The information related to such matters is almost negligible in all sectors banking upon assembly line-related work. The available literature on OSH issues focuses on hazard identification, surface layer accident investigations, job satisfaction levels, and worker well-being (Sklet, 2004; Dahlke, 2015; Rout and Sikdar, 2017; Gan, 2019; Dempsey, 2021). Much deeper context-specific hazard identification/ elimination, accident investigations/ mitigation, and negative work-related consequences in the FMCG sector are unknown, and mitigation strategies adopted to curtail those thus remain hidden (Singh and Karmakar, 2022; Singh and Karmakar, 2023). Context-specific OSH issues and hazard identification and elimination aspects related to assembly line work need to be explored to improve the existing scenarios.

2.3.7 Design interventions as mitigating strategies (physical and virtual)

Specifically, the design interventions to improve assembly line-related work about workstation design, work accessories design, and furniture design are not readily available. Many other design interventions are witnessed in other manufacturing industries (non-assembly work), which have positively affected the prevailing working conditions. Such studies indicated that with the appropriate type of ergonomics, there would be improvements in quality, productivity, working conditions, OSH, reduction of rejects, and overall profit (Scott, 2009; Dianat et al., 2017). Several extensive workplace design interventions have been implemented in the USA's poultry division by OSH administration (Occupational Safety and Health Administration, 2016). Some researchers proposed the shopfloor layouts as design intervention to increase productivity; however, these mainly focused on engineering concerns, and ergonomics of the design factors and work environment were the least concerned in these interventions (De Carlo et al., 2013; Putri and Dona, 2019; Kovács, 2020). Few other researchers have adopted another approach to improving the condition of the workplace from ergonomics and design perspectives. They implemented Virtual Ergonomic Analysis using several Digital Human Modeling and Simulation (DHMS) techniques where digital representations of humans were inserted into a simulation or virtual environment to facilitate the prediction and safety/performance (Demirel and Duffy, 2007). Such research has been carried out primarily in the automotive sector using DHMS to improve vehicle design, considering various anthropometric data and dimensions (Dukic et al., 2007). DHM was used in an industry that was engaged in heater manufacturing. It intended to design an ergonomic workstation and assembly line for worker safety (Longo and Mirabelli, 2009). Similar software was used in the mattress production unit to improve the mattress production processes by evaluating the operators' visual and postural aspects and, based on that, implementing design ergonomic interventions (Vallone et al., 2015). However, the use of DHM technology in Industrially Developing Countries (IDCs) is not very prevalent, and scanty literature exists. Within IDCs, Indian researchers successfully deployed context-specific design interventions to improve the working conditions of the Indian chemical conversion coating and injection-molded plastic manufacturing industries using DHM (Karmakar and Solomon, 2018; Sanjog et al., 2019). Several researchers have also pointed out that assembly industries are under a lot of pressure in today's worldwide competition. There is a clear link between workstation design and worker discomfort within these industries (De Looze et al., 2005; Dempsey et al., 2010).

2.4 Ergonomics: Workplace Evaluation Tools/ Techniques and Research

Ergonomics plays a vital role in improving worker safety, overall worker well-being, and productivity improvement on industrial shopfloors. Numerous ergonomic evaluation techniques/ tools exist for conducting ergonomic evaluations in various work domains of industrial shopfloor work. The following sections and subsections discuss the available ergonomic tools and techniques that can be used per the research context to evaluate workplaces for the prevalence of ergonomic stressors, hazards, and various other factors negatively affecting the workplace. Correctly identifying ergonomic evaluation tools (per research context) and their application on the shopfloor and OSH evaluation would ultimately enable researchers/ industrial designers/ engineers to develop appropriate solutions through innovative design and behavioral changes.

2.4.1 Physical ergonomics research

Worldwide, researchers use various physical ergonomic tools in the industrial arena to conduct ergonomic evaluations for the early detection of MSDs and to provide mitigating solutions for prevailing ergonomic hazards. These physical ergonomics tools comprise questionnaires, checklists, postural and load evaluation tools, etc. These tools can further be classified as objective and subjective evaluation techniques based on the result outcomes of the data analyzed. In conjunction with these tools, various ergonomic laboratory equipment (anthropometric kits, goniometers, force dynamometers, etc.) and various bio-electrical signals, viz. Electromyograph (EMG), Electrocardiograph (ECG), and Electroencephalograph (EEG) are being used for workplace ergonomic evaluations (Trask et al., 2010).

2.4.1.1 Subjective assessment tools

These tools primarily consist of questionnaires administered to report levels of MSDs and discomfort among various shopfloor workers under observation. As individual responses of the subjects are recorded based on their perception, the responses vary and are thus subjective in nature. Researchers have widely used varied subjective questionnaires, viz. Nordic Musculoskeletal Questionnaire (NMQ), Dutch Musculoskeletal Questionnaire (DMQ), National Institute of Occupational Safety and Health (NIOSH) discomfort survey, etc., for recording responses for this purpose (Marras and Karwowski, 2006a; Marras and Karwowski, 2006b; Bridger, 2017).

2.4.1.2 Postural evaluation tools

The vast majority of researchers on the industrial shopfloor have used physical ergonomic tools like Rapid Upper Limb Assessment (RULA), Rapid Entire Body Assessment (REBA), Ovako Working Posture Analyzing System (OWAS), etc., for conducting posture evaluations and suggesting remedial measures for MSDs prevalent over there (Marras and Karwowski, 2006a; Marras and Karwowski, 2006b; Bridger, 2017).

2.4.1.3 Work effort and fatigue measurement tools

Researchers have also used several ergonomic tools to measure the exerted work effort and fatigue level of the shopfloor workers under consideration. Among such tools, the Borg Rating of Perceived Exertion Scale, Hand Activity Level (HAL), Muscle Fatigue Assessment Method (MFA), etc., have been widely used by researchers (Radwin et al., 2015; Bridger, 2017).

2.4.1.4 Repetitive action level assessment tools

In several occupations that require high repetitive action levels, the researchers have used ergonomic assessment tools like the Occupational Repetitive Action (OCRA) method to evaluate the risk factors associated with the particular repetitive task based on the parameters, viz. repetition rate, the force exerted, awkward posture and movements, and recovery period provided (Marras and Karwowski, 2006b; Rana et al., 2021).

2.4.1.5 Back injury risk assessment and weight recommendation tools

On industrial shopfloors, the researchers have widely used the NIOSH Lifting Equation to assess the risk of back injury due to heavy load carrying and have suggested the recommended weight limits for carrying safe lifting tasks (De Faria Silva et al., 2018). Similarly, for lifting tasks while carrying the weight, the researchers have administered Snook Tables to recommend safe weight limits for intended purposes (Russell et al., 2007). Depending upon the characteristics of the FMCG sector, where high-paced assembly line work, highly repetitive hand/ wrist movements, and frequent Manual Material Handling (MMH) work exists; in that context, the researchers need to minutely study the work context (task context) and accordingly need to determine appropriate physical ergonomic evaluation tools (Rajendran et al., 2021). For example, for repetitive finger, wrist, and hand movements, precision gripping, and twisting work, OCRA and MFA might be more beneficial. It is also essential to understand that the posture varies across the workstations. Sometimes, it may be sedentary (sitting posture), where RULA could be applicable. On the other hand, REBA might be relevant in situations where the whole body movement, like carrying and lifting, is involved.

2.4.2 Cognitive ergonomics aspects

In industrial shopfloor activities, both physical and cognitive features are involved. Every task essentially involves cognitive parameters such as thinking, deciding, calculating, looking, searching, etc., for better performance to accomplish the job task. In such a scenario, the cognitive task elements become critical, and cognitive ergonomic evaluation tools are required for proper task analysis.

2.4.2.1 Subjective assessment tools

Researchers are widely administering psychosocial questionnaires to evaluate the working style, job stress, and other cognitive loading elements among shopfloor workers to promote employees' overall well-being. Researchers use the Job Stress Questionnaire (JSQ) to evaluate cognitive parameters like workload, role conflict, role ambiguity, and underutilization of abilities. The Work Style Questionnaire (WSQ) is widely used on industrial shopfloors to evaluate behavioral and work style parameters. In addition, the NIOSH Generic Job Stress Questionnaire is further administered to observe the existing mental hurdles on the shopfloor minutely (Marras and Karwowski, 2006a; Marras and Karwowski, 2006b; Bridger, 2017). It includes various other factors, such as individual, buffer, and non-work factors, that contribute to employees' mental condition and cognitive loading.

2.4.2.2 Mental load evaluation tools

Overall assessment of physical, mental, and temporal loading and corresponding satisfaction and induced fatigue level is vital for successfully evaluating cognitive loading induced by a worker’s task. National Aeronautics and Space Administration – Task Load Index (NASA-TLX) is one such subjective tool for measuring the workload of workers engaged in tasks under observation (Puspawardhani et al., 2016). Various other bio-electric potentials, like EEG, EMG, etc., are used to measure the worker's cognitive load. Besides, Functional Magnetic Resonance Imaging (fMRI), Heart Rate Variability (HRV), etc., enable the researchers to measure the brain and heart activity respectively to assess the cognitive loading being induced by the task under observation. Researchers nowadays use Magnetoencephalography (MEG) as an advanced technique to measure brain activity using very sensitive magnetometers. Researchers often use the Galvanic Skin Response (GSR) to map the Electrodermal Responses (EDRs) to assess the relationship between a worker's psychological state and his environmental events (Marras and Karwowski, 2006b; Bridger, 2017; Pykett and Paterson, 2022). As the high-paced assembly line work, high man-machine pacing, highly repetitive hand/ wrist movements, and frequent MMH work are fundamental to FMCG work, cognitive evaluation tools like NASA-TLX can be applied to evaluate the work task complexity and its interrelationship with induced fatigue level and job satisfaction or frustration levels to propose ergonomic design interventions as mitigation strategies.

2.4.3 Environmental factors

Environmental factors play a vital role in worker's performance and productivity. On any industrial shopfloor, these must be taken care of minutely to keep the working conditions human-friendly and congenial for human working. Researchers across the industrial sector have widely worked on various environmental sectors to promote ever-increasing safe, healthy, and pleasant working environments.

2.4.3.1 Illumination

The illumination level on industrial shopfloors contributes significantly to overall productivity. Researchers have focused on determining the optimum illumination level required for various industrial activities across different industrial sectors. They have also researched the OSH effect on workers due to existing illumination levels and other ergonomic stressors due to poor illumination levels (Bridger, 2017; Hernandez et al., 2021). Illumination level measurement in Lux values is important in this context. Specifically, for FMCG work, illumination is the critical parameter for success. The FMCG industry is alternatively known as the 'make and pack' industry. Packaging activities remain at its core. For effective packing activities, proper inspection of printed label graphics (batch number, quantity, etc.), warehouse management (stacking raw material and finished goods), and well-illuminated shopfloors and warehouses are of the utmost importance.

2.4.3.2 Temperature

Carrying out smooth operations on industrial shopfloors depends upon the existing temperatures in the workplace. Worker performance is achieved only if the working temperature is suitable to human body conditions and they feel comfortable working within those temperature limits. Researchers have determined various temperature levels for better human performance across different industrial sectors and their integral work activities (Ross-Pinnock and Maropoulos, 2016; Bridger, 2017; Hernandez et al., 2021; Foster et al., 2022). Thermal assessment is conducted by taking three different air temperature measurements, viz. Dry Bulb Temperature (DBT), Wet Bulb Temperature (WBT), and Globe Temperature (G.T.). Among these three measurements, the G.T. is the most important factor in assessing the true nature of the thermal environment, as it accounts for the effects of radiant heat. Researchers prominently use the Wet Bulb Globe Temperature (WBGT) to estimate the effect of temperature, humidity along with the wind speed (wind chill), and visible and infrared radiation on shopfloor workers. WBGT is calculated by the formulae below:

$$\text{WBGT (out)} = 0.7\text{WBT} + 0.2\text{GT} + 0.1\text{DBT}$$

$$\text{WBGT (in)} = 0.7\text{WBT} + 0.3\text{GT}$$

Compact advanced equipment may be used for measuring these parameters. A heat stress monitor can measure DBT, WBT, and G.T., whereas a micro-psychrometer can give direct readings of temperatures (WBT, DBT), relative humidity, and dew point. Temperature (heat) remains the primary focus for the FMCG sector. Shrink packaging is the most frequent essential packaging activity on the FMCG shopfloor. The shrink packs coming out of the heated oven are tedious and need proper addressing by the researchers. Besides, the high pace of FMCG assembly line activities leads to high heart rate (H.R.) levels and enhanced sweating due to exaggerated adrenal hormone secretion. High-focused attention level requirements coupled with high cognitive loading increase the drudgery. In such conditions, the optimum ambient temperature levels need to be assessed and maintained to achieve productivity (Marras and Karwowski, 2006b; Bridger, 2017).

2.4.3.3 Humidity

High moisture content existing on the shopfloor leads to increased perceived temperature and negative worker productivity due to irritation and non-comfort. Similarly, low moisture content has negative consequences too. Proper moisture content must be maintained to keep the workplace comfortable for working therein. Researchers have determined various moisture levels for different workplace environments to achieve the desired level of production output (Hernandez et al., 2021; Foster et al., 2022. 'Psychrometric Charts' are often used to calculate relative humidity by assessing the DBT and WBT existing on shopfloors. A micro-psychrometer is the most important equipment for directly reading temperatures (WBT, DBT), relative humidity, and dew point. For the FMCG activities, the moisture content is of primary concern as most FMCG products use chemicals that contain moisture, adding to the already existing moisture levels and thus increasing the humidity content over workplaces. Determining optimum humidity levels on FMCG shopfloors should be a primary concern for shopfloor managers.

2.4.3.4 Airflow

To achieve the right conditions for work on the shopfloor, not only do the temperature and humidity play a vital role, in fact, the airflow becomes an essential factor. Correctly saying, it is the optimum combination of all these three parameters that makes the workplace environment comfortable. Shopfloor environments are often contaminated with dust, vapors, gases, smoke, or other substances created by the production processes. These airborne contaminants might be toxic, flammable, or explosive. Often, air quality deteriorates due to a buildup of odors, excessive humidity and heat, and carbon dioxide within factory premises. Airflow has both physiological and psychological effects on the workers, like decreasing skin temperature (physical) and creating comfortable or uncomfortable sensations (psychological). Effective ventilation systems must be installed on shopfloor premises to keep the surrounding air clean and eliminate foul smells, stale air, etc. Indoor Air Quality (IAQ) assessment is the most important measure to determine the air quality within an indoor space, i.e., freshness, cleanliness, circulation level, etc. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE), American National Standards Institute (ANSI), and OSHA guidelines may be considered for proper IAQ measurements and for effective ventilator designs and placement as per the context (Marras and Karwowski, 2006b; Zhang et al., 2016; Bridger, 2017). Airflow and effective ventilator systems become essential for the FMCG shopfloor as FMCG products readily use chemical compositions in their products, as these are 'make and pack' industries. Menthol is generally used in personal care FMCG products, giving a cooling sensation to the skin and sometimes irritation to the eyes. Many other chemicals suspended in the air within FMCG factory premises exist, which need to be expelled with adequate airflow and ventilation.

2.4.3.5 Noise

Noise is another environmental factor that the researchers are actively studying to detect the optimum levels for safe working conditions on the shopfloor. Excessive noise and sound levels cause irritation and temporary or permanent threshold limit shifts. Noise is a physical stimulus. It can be measured and quantified with instruments like dosimeters, transducers (microphones), and Sound Level Meters (SLM) and is measured in decibels. The researchers often perform measurements of Time Weighted Average (TWA) exposure and noise dose for specific periods (Denisov, 2018). OSHA standards requirements for various SLM, TWA, Noise Dose, etc., become essential for achieving preferred and optimum noise levels on shopfloors. Particularly in FMCG, while packing the solid/ liquid contents in bottles (glass/ plastic), the induced noise is a major irritant for the workers. The fast-moving bottles on the conveyor belt often strike/collide with each other, generating lots of noise, which needs to be adequately addressed to keep the noise level under safe limits. Noise level measurement at other FMCG stations is equally important to understand context-specific needs in this domain.

2.4.3.6 Vibrations

Vibration is another environmental concern. However, it is a less common problem but affects any industrial shopfloor a lot. Whole Body Vibration (WBV) and shakiness tend to increase heart rate, oxygen uptake, and respiratory rate. It leads to fatigue, insomnia, headaches, and uneasiness. Raynaud's Syndrome, or dead fingers, is one of the major vasospastic syndromes associated with Hand and Arm Vibrations (HAV). Vibration measurements become important on any industrial shopfloor, and these are measured in Hertz. WBV measurements are generally made using a very lightweight pie-shaped instrumented hard rubber disc. Similarly, the HAV measurement uses three small, lightweight crystal accelerometers that are mounted to a small metal cube. These vibration measurements are often carried out in accordance with guidelines published by the International Standards Organization (ISO), ANSI, NIOSH, and OSHA as per the context (Vihlborg et al., 2017; Bridger, 2017). On FMCG assembly lines, vibration becomes a primary concern. On packing stations that are integrated with assembly lines, the workers tend to sit closely (often colliding with) due to narrow lateral clearance margins and are exposed to

WBV and HAV. In such conditions, the vibration measurements and their ill-effect measurements need to be addressed as a priority in the FMCG sector.

2.4.4 Safety aspects

Industrial safety is vital in promoting occupational safety, worker well-being, and productivity across various industrial sectors. Every industrial shopfloor is exposed to several hazards, viz. physical, chemical, mechanical, biological, electrical, ergonomic, environmental hazards, etc. These hazards lead to accidents if not correctly identified and taken care of at early stages. Industrial accidents and accident investigations are scantly reported across the published literature. Underreporting of data regarding accidents and injuries is very common in developed nations and hampers the prospective mitigating research toward the betterment of prevailing adverse scenarios (Kyung et al., 2023)

2.4.4.1 Hazard and risk assessment tools

Several hazard identification tools can be deployed regularly to check for early detection of prevailing hazards on the industrial shopfloor. Preliminary Hazard Analysis (PHA), Hazard Analysis (HAZAN), Chemical Hazard Analysis (CHA), Hazard and Operability study (HAZOP), Risk Analysis, etc., can be implemented for early detection of hazards (Hyatt, 2018). Various combinations of these checklists should be deployed at regular intervals to ascertain the safety of shopfloors.

2.4.4.2 Accident investigation techniques

Hazards, once triggered, lead to industrial accidents. In an unfortunate event such as an accident, the accident investigation becomes very important. Accident investigation helps to determine the key factors that lead to the event, and it further helps to ensure that such events do not occur in the future. Failure Mode and Effect Analysis (FMEA), Technique of Review (TOR), Event Tree Analysis (ETA), Root Cause Analysis (RCA), Fault Tree Analysis (FTA), etc., can be implemented both before and after the event to investigate the causes leading to an accident (Theodore and Dupont, 2012; Hyatt, 2018). The FMCG shopfloors readily store the raw material (flammable chemicals, etc.), uses high-speed moving machinery parts (assembly line, heat ovens for shrink packing, etc.) and heavy load handling machinery in warehouses being as these are typically 'make and pack' industries working on Just in Time (JIT) model. As such, all these hazard identification and risk analysis techniques become essential for FMCG engineers/

managers. In addition, appropriate awareness of Personal Protective Equipment (PPE) needs to be generated.

2.4.4.3 Work-standardization activities and research

Work standardization is essential on every shopfloor to keep it productive and non-chaotic. It is a method for developing best practices and procedures that provide ease of working and enhance overall work productivity of the tasks upon which these are implemented. Researchers have readily focused on continuous improvement activities (Kaizens) to promote work standardization activities. Implementation of 5S, visual management, and standardization of processes have been important for the researchers. For standardization of work processes, Method-Time-Measurement (MTM), time and motion studies, Maynard's Operation Sequencing Technique (MOST), Takt Time improvement, etc., were employed in industries (Salvendy, 2001; Charron et al., 2014; Zandin and Schmidt, 2020). The Overall Equipment Efficiency (OEE) is used for work measurement and productivity enhancement in the FMCG sector. These activities are of prime importance, especially in the FMCG sector, where assembly line work is inevitable. Takt Time improvement, Kaizen activities with thorough ergonomic considerations, and visual management can be very beneficial for FMCG work, considering FMCG work parameters. In addition, rigorous research to find the best possible spatial arrangement of workers and workstations across the FMCG assembly lines may be initiated as the FMCG workstations are spread across both sides of the assembly lines.

2.5 Discussion

A thorough review of the existing literature provides several insights into the importance of the FMCG sector at the global, national, and regional levels. It is an important sector from a global GDP and employment contribution standpoint. It is alternatively known as the 'make and pack' industry, wherein low-cost, high-volume products are produced on high-paced assembly lines utilizing mass manufacturing strategies and packed and distributed for the daily consumption needs of millions of people worldwide. Most of the information about ergonomics and OSH-related issues concerning assembly line work comes from the automotive and electronic component manufacturing units. FMCG assembly lines are distinct from those assembly lines. Table 2.4 depicts the characteristics of the assembly lines in these industrial sectors. A thorough understanding of these characteristics helps the researcher/ engineers plan the ergonomic assessments and corresponding tools/ techniques for conducting such ergonomic evaluations. The researcher needs to understand the distinct characteristics of the FMCG work processes, peculiar work activities, and context-specific job activities to promote safety and well-being on the FMCG industrial shopfloor. Several ergonomic tools/ techniques are available for physical, cognitive, and organizational ergonomic evaluations and have been used by researchers in various industrial shopfloor-related works for improvements. The effective use of ergonomic tools/ techniques is lesser known within the FMCG sector, where the primary focus remains on using tools/ techniques for achieving production/ operation excellence. Identification of appropriate ergonomic tools/ techniques for promoting ergonomics and OSH–related studies and improvement efforts is required. A critical understanding of FMCG shopfloor activities' peculiar work characteristics and work parameters and their mapping with the available ergonomic tools/ techniques may be beneficial in this direction.

Table 2.4: Characteristics of assembly line-oriented industries: An overview. (Source: author)

Work activities/ Production parameters	Automotive assembly lines	Electronic component manufacturing assembly lines	FMCG assembly lines
Assembly line pacing	slow-paced	slow-paced	highly paced
Workstations across the assembly line	single side	single side	both sides
Nature of work activities	long cycled - moderate repetitive work	moderate cycled - moderate repetitive work	short cycled - highly repetitive work
Work posture	moderate standing/ sitting	generally sitting	prolonged standing
Prominent body parts involved	upper extremities	hands and forearm	wrists and fingers (packaging, bottle feed, rework, etc.)
Cognitive load (man-machine pacing)	low	low	very high
Product type & product volume	high-cost low-volume	moderate-cost moderate-volume	low-cost high-volume
Essential production activity	single part fixing	assembling components	manual carton packing and dispatching (high pace)

Various combinations of the available tools/ techniques may be deemed appropriate for the intended ergonomic evaluations as per the context (workstation being evaluated, work activity under consideration). The ergonomic assessment using such tools will help improve the OSH scenario and overall worker well-being and improve product quality and production efficiency.

2.6 Conclusion

An in-depth exploration of the available literature provided information about various aspects of the FMCG sector, viz. background, current scenario, focus area of research, and prevailing levels of ergonomics and OSH-related attentiveness in the domain. The exploration of literature pertaining to ergonomics-related research in industrial domains provided insights into the various available ergonomics tools/ techniques for ergonomic assessment and approaches toward providing mitigating solutions. A few of the observations/ insights are provided below:

- Most of the research conducted in the industrial arena indicates that the research carried out within the industrial sector from an ergonomics perspective remains limited to diagnostic studies. Such studies focus on diagnosing the prevalence of MSDs and other ergonomic stressors on the shopfloor. They focused on providing recommendations from the OSH perspective, including available standard guidelines (preventive measures, physical exercise, therapy, rehabilitation measures, etc.) that may improve occupational health.
- A few researchers proposed engineering/ design interventions as mitigating solutions, viz., shopfloor layouts, context-specific workstation redesign, etc. However, such interventions remained limited to virtual ergonomic evaluations and lacked practical implementation. Such approaches focused on and tried looking into and considering the standardized work practices of industrial shopfloors.
- The research within the FMCG sector from an ergonomics aspect is almost negligible. The research in this domain has primarily focused on production/ operation excellence-related aspects.
- Owing to government support and encouragement, FMCG is the fastest-growing sector in India, especially in the northeastern states.

Researchers worldwide have reported several OSH-related concerns with assembly-related work. FMCG product manufacturing primarily depends upon such work practices; however, very little is known about them and their associated aspects. In the wake of the paucity of available information related to OSH concerns regarding FMCG work, there is a dire need to explore the FMCG sector from ergonomics and OSH perspectives, especially in IDCs. A preliminary ergo-audit conducted on the FMCG manufacturing units to assess the OSH scenario, the critical area of concern, and an approach toward providing an appropriate mitigating solution is presented in the upcoming chapters.

3

Preliminary Ergo-audit of FMCG Industries in North-east India

Abstract

The literature review indicated the paucity of reported research from the FMCG domain, especially from an OSH and ergonomics perspective. Most of the information regarding FMCG working and associated issues comes from the automated food processing segment of FMCG, which is typically located within developed nations. The semi-automated personal care product manufacturing segment is the most dominant segment of FMCG in IDCs. However, very little is known about its work practices and associated OSH-related issues. A rigorous ergo-audit was conducted on the shopfloor of twenty FMCG manufacturing units in northeast India to fill this gap existing in the purview of ergonomics and OSH scenarios within the FMCG sector. These units manufactured personal care products utilizing a large labor force within semi-automated setups. From ergo-audit, several ergonomic stressors, OSH-related issues, and bottlenecks to productivity were identified that pose safety risks and lower productivity. Various context-specific non-standardized work activities related to FMCG work practices were observed and noted. For practical concerns and to steer research forward, a critical area of concern was selected from the identified OSH issues utilizing the card sorting technique. The non-standardized work activity of defective pouch/ sachet rework was identified as the most critical activity, and innovative design interventions in the form of safety-enriched tools/ apparatus were sought as a mitigating solution. Considering that the same solution may probably not be applicable for the FMCG manufacturing units working at varied levels of production scale, representatives of small, mid-scale, and large-scale manufacturing units were selected for further explorations for research work, as planned.

3.1 Introduction

From the literature review, it was found that the FMCG industry is an important sector worldwide. There lies the paucity of research in the FMCG sector from ergonomics and OSH perspectives. Most of the research into the FMCG domain focuses on the areas of production/ operation excellence. Ergonomics - the science of man-machine compatibility is often lacking in such FMCG manufacturing setups and leads to several ergonomic stressors and OSH issues. Most of the information about FMCG work and associated ergonomic issues hails from the automated food processing segment that is typically present in developed nations.

In contrast, the FMCG sector in IDC remains semi-automated and labor-intensive. FMCG in IDCs, especially in countries like India, focuses heavily on producing personal care goods, and such segment accounts for 50 percent of the FMCG market share. In the FMCG sector, the current research considers the Indian FMCG manufacturing units engaged in producing personal care goods that are often manufactured through production processes that remain manually operated and semi-automated. However, few of their production processes remain automated, and mass manufacturing of FMCG products occurs. As there is a paucity of reported research on ergonomics and OSH-related issues from such FMCG manufacturing domains, there is a dire need to explore such manufacturing units from an ergonomics perspective.

In the initial phase of the current research, the rigorous survey of the FMCG manufacturing units engaged in personal care products and working under semi-automated production setups employing significant labor involvement was planned to understand the peculiar work activities and work parameters of such industrial units. It was based upon the objective of studying and understanding the OSH-related issues prevailing on the Indian FMCG shopfloors and subsequently identifying the most critical area of concern among the identified OSH-related issues that must be prioritized for addressing and enactment. The initial survey seeks answers to the research question that emerged in the present research context: 1) What are the various OSH-related issues prevailing at manual/ semi-automated Indian FMCG manufacturing units? 2) Which area of concern from OSH purview must be prioritized according to the shopfloor workers, manager/ supervisors, and factory management? A preliminary ergo-audit was conducted for it, and the observations from such an ergo-audit are presented in the following sub-sections.

3.1.1 Ergo-audit

Globally, across the varied industrial domains, ergonomics plays a vital role in improving man-machine interfaces and results in system improvements that promote occupational well-being (Salvendy, 2012; Bridger, 2017; Kogi et al., 2019). Several nodal agencies promoting ergonomics and associated areas of concern remain proactive in providing and implementing standard guidelines (in the form of checklists and standards, for rigorous enforcement at workplaces ranging from offices to complex industrial workplaces (Niu, 2010). Adherence to those leads to several benefits, including safe and productive work environments. The International Ergonomics Association (IEA), International Labor Organization (ILO), and OSHA are a few such prominent nodal agencies. An ergonomic audit (hereinafter referred to as ergo-audit) based on the standard guidelines and checklists prepared by these agencies becomes a handy tool to promote a productive and efficient work environment, especially in industrial workplaces that often engage manual labor (Alpaugh-Bishop, 2012; Ahmadi et al., 2017; Drury and Dempsey, 2021).

From the interpretation of the ergo-audit from the standard definitions provided by nodal agencies working in the ergonomics domain, it can be ascertained that ergo-audit is a systematic evaluation of all the components in a workplace that impact workers' well-being, comfort, and productivity. It entails assessing how well the tasks and work environment fit the abilities and constraints of employees. It helps find possible areas for improvement, and putting in place suitable ergonomic solutions is the ultimate objective. Organizations can ensure that the layout of their workstations lowers the risk of musculoskeletal problems, lessens fatigue and discomfort, and improves overall job performance by performing an ergonomics audit. This holistic approach is based on realizing the fundamental fact that each person is distinct, possessing a range of physical capacities and limitations. It acknowledges the significance of establishing a work environment that fosters employee success. From this discussion, it is noteworthy that an ergo-audit is an essential tool that can be applied to workplaces to ensure a safe and healthy environment, leading to well-being and productivity. A rigorous ergo-audit is generally implemented by accomplishing the following basic tasks/ steps, as elucidated in Table 3.1.

Table 3.1: Ergo-audit – key activities involved. (source: author)

Main Activity	Sub-tasks Involved
Preliminary Research (understanding context-specific human factors requirements & associated potential risks involved)	▪ initial familiarization with the work activities and jobs being performed ▪ understanding the critical work parameters involved in job/ tasks ▪ gathering and referring information about available guidelines for good practices in such tasks
Walkthrough Assessment	▪ conducting a thorough walkthrough of the shopfloor ▪ in-depth observation of the workers performing their work activities ▪ looking for signs of discomfort, the stress involved ▪ observing awkward postures and other ergonomic stressors involved, viz. high repetitions, high force exertions, etc. ▪ observe risk-involved activities ▪ notice poorly designed or ill-equipped workstations ▪ keenly observing other unnoticed areas of concern ▪ collecting visual evidence (photographs/ videos if permitted)
Interviews with Stakeholders	▪ discussion with workers, safety managers, office/ factory management ▪ gain insights into their woes, worries, and discomforts experienced while performing the jobs/ tasks ▪ understanding their concerns and taking suggestions for improvement
Documentation	▪ preparing a record of collected data (from field observations) ▪ preparing in-depth notes along with proper visual evidence and justification
Analysis	▪ a thorough review of collected data (from field observations) ▪ identifying the OSH and safety-related issues ▪ prioritizing such issues for further action implementation
Action-plan Development	▪ developing systematic action plans to provide mitigating solutions (engineering, design, behavioral, managerial solutions, etc.) ▪ proposed solution development and implementation

3.2 Preliminary Ergo-audit of FMCG Industries in North-east India

Aligned with the research questions and objectives of the current research, an ergo-audit as per the IEA, ILO, and OSHA guidelines (International Ergonomics Association, 1996; Cal/OSHA Consultation Service, 1999; IEA and ILO, 2015) was planned on the shopfloor of semi-automated and labor-intensive FMCG manufacturing units located in northeastern India owing to their tremendous growth, employment potential and contributions to the GDP growth in the region and country. Since such ergo-audits involve human participants, formal approval from the Institute Human Ethical Committee was taken (Appendix A.1). It was the right time to identify any lacunae occurring in these industries from an ergonomic perspective. It primarily aimed to understand the FMCG operational activities and identify ergonomic stressors that hamper overall productivity and safety.

3.2.1 Methodology

Foremost, data regarding the industries working in the FMCG sector within northeast India was gathered from various government records and reports published in gazettes and available on government websites (NEIPP, 2007; NEIDS, 2017). It was found that the government allotted several prominent FMCG industries space in Industrial Parks (IPs) spread across Guwahati, Sonitpur, Tinsukia, Nalbari, and other areas. Guwahati district remained the hub of such FMCG manufacturing units. Brahmaputra Industrial Park (BIP), Export Promotion Industrial Park (EPIP), Bamboo Technology Park (BTP), and Tea Park (TP) were the prominent IPs established by the government in Guwahati (NEIPP, 2007; NEIDS, 2017, IIP, 2019). The noticeable FMCG units located in these IPs were approached. Formal permission to conduct an ergonomic survey to understand peculiar FMCG work activities to identify ergonomic stressors and other bottlenecks to productivity was sought. Formal permissions were obtained from these prominent FMCGs, Non-disclosure Agreements (NDAs) were signed with factory management, and informed consent (if any) was obtained from participants wherever they were involved. (Appendix A.2, A.3).

Initially, the preliminary ergo-audit was conducted at the twenty FMCG manufacturing units located across Assam. These manufacturing units were working at varying scales of production levels, viz. mega, large, and small-scale production. These units were engaged in manufacturing low-cost, high-volume FMCG products under semi-automated setups, and a large workforce was involved in their manufacturing requirements, especially in packing, dispatching, and various other non-standardized work activities. A few of their production processes remain automated. Parallel assembly lines spread across the production shopfloor were involved in manufacturing several personal care products, viz. hair oil, shampoo, serum, cosmetic products, hair dye, Vaseline, etc. Identical products with varying sizes were produced on different workstations, e.g., hair oil pouches/ sachets with 2 milliliters (ml), 3ml, 5ml, etc., and many other such products that were packed in plastic bottles, glass bottles, pouches/ sachets.

Careful assessment of the peculiar work activities of the FMCG shopfloor (bottle/ sachet filling, packing of finished goods, reworking of defective goods, etc.) was minutely conducted (Singh and Karmakar, 2021). Regular visits throughout the working days (in general and night shifts) at these manufacturing units were carried out for six months (as per availability and approval), production operations engaged thereof were minutely observed, and limited photographic evidence was collected. Video permissions were not granted. These rigorous field observations focused on understanding the critical parameters of FMCG manufacturing, especially over the workstations involving significant labor employment. IEA, ILO, and OSHA guidelines and checklists were followed to conduct an ergo-audit on these FMCG shopfloors. All the data gathered about FMCG shopfloor activities through ergo-audit and field observations were scrutinized to identify prevailing ergonomic stressors and operational bottlenecks to productivity. These are discussed in subsequent sections and sub-sections.

3.3 Field Observations

Field observations at the studied manufacturing units in northeast India revealed the prevalence of several ergonomic stressors and productivity bottlenecks. These are discussed in the following sub-sections.

3.3.1 Awkward postures

Prima Facie, many work instances spread across various FMCG workstations indicated the adoption of awkward postures. Workers tend to adopt awkward postures to carry out their routine activities at their workstations. These situations prevailed in all manufacturing units under observation. It was observed that workers were working at shoulder height, colliding with machine parts while sitting on workstations, excessive bending, etc. Figure 3.1 (a), (b), and (c) depict some of such instances where workers are exposed to awkward postures. Prolonged standing work posture for a period ranging from 8 hours to 12 hours was common among all assembly line-related work activities. Short-cycled, highly repetitive work was highly prevalent on such assembly lines and required fine finger movements and wrist involvement. The quality inspection workstations required high visual and cognitive requirements.

(a) awkward seating
(no lateral clearance, no footrest)

(b) awkward bending (prolonged standing, high force, heavy equipment held)

(c) working at shoulder height (awkward posture)

Figure 3.1: Field observations (awkward posture adoption). (Source: author)

3.3.2 Ill-equipped workstations/ inadequate tools

Inadequate workstations were witnessed on FMCG shopfloors, and workers adjusted themselves on available workstations to perform their respective jobs. Improper furniture (stools, benches, chairs, etc.) exists at such workstations. These are generally in-house fabricated and lack the basic features (lumbar support, arm support, footrests, etc.) required for performing prolonged work activities efficiently. Figure 3.2 (a), (b), and (c) depicts a few such ill-equipped workstations.

(a) working at height
(no lumbar support, shoulder height working)

(b) ill-equipped workstation
(improper seating, no footrest)

c) awkward seating (prolonged sitting, no footrests)

Figure 3.2: Field observations (ill-equipped workstations). (Source: author)

(a) inadequate tools (sharp cutter/ blade used, forceful hand squeezing)

(b) inadequate tool (slippery floor, the spilled liquid being collected with dustpan and wiper)

Figure 3.3: Field observations (inadequate tools). (Source: author)

Besides, inadequate tools exist for several key work activities, and workers tend to use and adapt to jugaad tools. In haste to perform their duties effectively, they often use inadequate/ inappropriate and sharp tools, leading to injuries. Figure 3.3 (a) illustrates the use of a sharp cutter blade and forceful manual hand squeezing, and figure 3.3 (b) depicts the use of improper/ inadequate tools to collect oil from the wet, slippery floor (using a dustpan and wiper available off the shelf). Factory management is, however, concerned about such issues, tries to refrain from using such tools, and seeks context-specific solutions in this regard.

3.3.3 Improper Kaizens implemented

The FMCG units are focused on implementing lean manufacturing principles into their operations (Kumar et al., 2019). Kaizen (continuous improvement activities) are implemented on a routine basis in various FMCG operations and at different workstations. These primarily include in-house fabricated workbenches, furniture, work accessories, small jigs, fixtures, etc.

(a) paper packing inserted to raise seat height to accommodate well

(b) Kaizen (bottle holding tray provided, now forcing the worker to work without any lateral clearance)

(c) Kaizen (bottle holding tray provided for both sides working; it will force both workers without any lateral clearance)

Figure 3.4: Field observations (improper Kaizens). (Source: author)

It was observed that although the kaizens are being implemented, they are not very effective. Instead of improving productivity, they hamper it by leading to several ergonomic stressors.

Figure 3.4 (a) illustrates in-house workbenches developed under Kaizen activity. These workbenches are unable to cater to the anthropometric needs of the working population that uses them. They have to alter these as per their convenience using jugaad techniques like paper packing to raise the height (as in this case). At critical workstations, e.g., bottle feeding stations, additional holding trays are provided under Kaizen activity to cater to the need to hold empty bottles to load on the high-paced assembly line. These trays are attached to the standardized assembly line. They act well to contain the material but compel the worker to work too far away from the assembly line, leading to awkward postures (figure 3.4 (b)). It induces enhanced fatigue as workers working away from the assembly line stretch their upper extremities to reach the work zone. Insufficient lateral clearance due to these extended trays restricts the free space between the worker's body and the work accessory. In such a situation, the worker tends to lean and collide with the tray. It results in off-balancing the assembly line, and often, the vibrations from the machine-part-oriented assembly line are transferred to the worker's body. In-house fabricated material handling trays for both side working stations across the assembly line are depicted in Figure 3.4 (c). It poses the same problems to the workers working at these workstations.

(a) intermediate Kaizen implemented (thin steel guide)

(b) material getting choked (kaizen implemented station became fast; however, the next station is still slow, and desynchronization occurs)

Figure 3.5: Field observations (intermediate Kaizens and desynchronization). (Source: author)

At several workstations, impartial kaizens are implemented haphazardly at intermediate positions without thoroughly considering their effect on the previous and next workstations. Figure 3.5 (a), (b) illustrates one such example. In this situation, the implemented Kaizen can enhance the work speed at the implemented workstation. However, the next workstation has not been improved yet, and it cannot handle the increased capacity/ flow rate of products delivered from the previous workstation. As a result, the assembly line gets choked, and further problems are aggravated. The implementation of such intermediate Kaizens results in the complete desynchronization of the assembly line.

3.3.4 Non-standardized work practices

Having understood the peculiar work parameters of FMCG assembly lines during the field observation, it was noticed that workstations spread across both sides of installed assembly lines. Similarly, the additional work accessories were placed/ provided at both left-hand and right-hand positions of the worker's seating arrangement. In order to match the man-machine ratio and pacing of the high-speed assembly line, additional workers are added to the existing assembly line. A few identical workstations are on the right side of the assembly line, and the rest are on the other side. It was observed that principles of motion economy act as a boon for workstations located on one side of the assembly line. In contrast, the other side suffered (lower productivity) due to their location against the material flow. Several such instances were observed. Figure 3.6 depicts one such scenario from the carton packing station.

Figure 3.6: Field observations (non-synchronized carton filling activity). (Source: author)

Figure 3.6 depicts the existing scenario of carton packing involving four workers. Filled bottles coming at high speed from left to right. A filled carton needs to be passed to the next station located on the right side (beyond workers B and D). Here, in this case, four different workers are engaged in carton filling, and their jobs seem to be identical. Material flow (filled bottles) is proceeding towards them at a high pace of the order 140-160 bottles per minute. Despite four workers being engaged, the assembly line still choked as they were not available (able) to clear the assembly line at the required rate. By conducting a time-motion study of this group activity, it was observed that the workers on the right side were able to perform the work quickly, and the workers on the left were far behind. In addition, the worker working in the direction of material flow (worker A) was the most efficient of all. In this condition, worker A and Worker C had completed their task, so they are ideal now, as workers B and D have not yet completed their carton filling. They are not able to pass on their filled cartons to the next station, and the overall productivity hampers. Such non-standardized work activities resulting from the unplanned spatial arrangement of workstations are commonly observed on FMCG shopfloors.

3.3.5 Unsafe work activities

The FMCG shopfloor activities involve several critical work activities that differentiate these from other manufacturing units. Such exclusive work activities are often carried out in an unorganized and non-standardized manner and lack specialized context-specific tools and workstations.

(a) rework of defective pouches/ sachets in a sitting position

(b) rework of defective pouches/ sachets in a standing position

Figure 3.7: Field observations (unsafe work activities). (Source: author)

One such activity is the reworking of defective liquid-filled pouches/ sachets. It is carried out in almost every FMCG manufacturing unit and is a voluminous work activity. To recover liquid from the damaged pouches/ sachets, the workers cut the pouches/ sachets with sharp cutters/ blades/ scissors while working bare hands. A forceful manual hand squeezing of the cut pouches to drain the liquid is prevalent, spoiling their hands and leading to contamination of the liquid being extracted. Fig. 3.7 (a) and (b) depict two scenarios of this activity. No standardized workstation or tool exists for this activity. Cuts and injuries are common in such activity and are a significant concern for factory management. They seek an immediate solution to eliminate the use of sharp cutters/ blades and standard workstations for this prominent rework activity.

3.3.6 Unplanned facility layout planning

Most of these FMCG units are built upon industrial plots allotted by the government within IPs. Raw material storage units, main production area, warehouse, etc., have been managed within the allotted space only. Thorough ergonomic considerations have been ignored while commissioning the machinery at the inception. Improper layout for inventory area, work in progress, and finished goods are prevalent across the manufacturing units. Upon gradual development of the manufacturing units, within a few years of inception, the need for expansion occurred. To cater to this need, haphazard extensions have been done within the existing workspace. This leads to narrow passages, congested working areas, untidy workplaces, unorganized production areas, etc. It hampers the overall productivity of the manufacturing units.

3.3.7 Workshift duration

Prolonged working hours exit within these FMCG manufacturing units. These manufacturing units work round the clock for twenty-four hours within shifts of 12 hours and 8 hours. Most of these manufacturing units have two shifts of 12 hours, and only a few have three shifts of 8 hours. To comply with the statutory guidelines of the Factories Act 1948, the female staff works only in the general shift (daytime), and the male staff works during the night shift, too (Ministry of Labour & Employment, Govt. of India, 2024). As it is a 'make and pack' industry, a large number of the contractual workforce engaged in packing activities is common in these manufacturing units. Generally, this contractual workforce is unskilled and untrained.

3.3.8 Environmental aspects

FMCG products constitute several chemical combinations within their products, viz. cosmetic products, detergents, shampoo, hair oil, etc. The use of menthol is prevalent, too. Maintenance of Indoor Air Quality (IAQ), airflow, ventilation, ambient temperature, humidity, etc., is the area of concern within these manufacturing units. The final packing of the products is carried out using shrink packaging with heat ovens that generate a lot of heat on the production floor. Management of this heat dissipation is a major concern among factory management. Several FMCG products, like Vaseline, require a cold environment and must be managed accordingly.

3.4 Insights from Field Observations

During the frequent visits to the shopfloor of FMCG manufacturing units, several important observations related to their working and work environment were made, and these have been discussed above. A brief discussion focusing on the probable root cause of these problematic areas is presented in the following subsections:

3.4.1 Anthropometric mismatch

Awkward posture adoption in such industries results from an anthropometric mismatch between the worker population and workstations/ work accessories (Sanjog et al., 2019). Thorough consideration of body dimensions, range of motion, biomechanical parameters, etc., for devising appropriate workstations and accessories may help to curb the situation. Several researchers have taken such approaches in other manufacturing industries and helped to better the situation (Karmakar and Solomon, 2018; Sanjog et al., 2019; Colim et al., 2019). MSD prevalence and other associated OSH risks must be monitored regularly to curtail these in the early stages.

3.4.2 Ergonomic principles and design strategies

Ignorance towards ergonomics – the science of man-machine compatibility and ergonomic principles is common among workers and management in these industries (Shahnavaz, 2009). Continuous improvement activities (Kaizens) are being implemented without thoroughly considering ergonomic principles to develop in-house fabricated workstations and work accessories, leading to MSDs and other ergonomic stressors. Proper design strategies must be implemented with ergonomic principles to improve the situation (Singh and Karmakar, 2021).

3.4.3 Holistic approach for Kaizens

In haste to run daily routine affairs efficiently, the factory management and supervisors resort to haphazardly implementing Kaizens. Often, these are related to production/ operational aspects that are productivity enhancement measures and ignore human elements (Lämkull et al., 2009; Aljunaidi and Ankrah, 2014). A holistic approach needs to be considered when any Kaizen has to be implemented. These must be applied with consultation among various stakeholder departments (production, operation, quality, safety) and not be applied in a fragmented manner. The effects of any Kaizen implemented must be thoroughly assessed in advance, considering the whole assembly line as one unit.

3.4.4 Work standardization

Specifically for FMCG assembly lines, there is a need to understand the optimum position for placing workstations and workstation accessories across the assembly line. The spatial arrangement of these needs to be adequately determined to ensure that principles of motion economy are harnessed efficiently. As such, work standardization techniques may be helpful in such industries as implemented by other researchers within other industrial sectors (Lee et al., 1997; Das et al., 2007). Designing experiments among such group tasks to better assess the situations and determine the best spatial orientation of workers may prove beneficial.

3.4.5 Innovative tools and strict safety policies

Context-specific work and work activities remain integral to any manufacturing unit, and FMCG is no exception. Rework activities are one such activity on the FMCG shopfloor. These must be understood carefully, considering all the work elements involved to assess the specific needs of such jobs. Further, innovative context-specific design interventions may be deployed based on these needs to ensure safety and productivity among such tasks (Singh and Karmakar, 2021). Strict safety protocols and training for workers in this context must be chalked out, implemented, and regularly monitored for its implementation.

3.4.6 Workplace design and space management

Organized shopfloor layouts that meet specific needs are essential for any industrial unit. Researchers have greatly improved shopfloor in various industrial setups (Lee et al., 1997; Udosen, 2006; Suhardini et al., 2017; Li et al., 2021). Similar approaches may be considered at FMCG units as per the need for FMCG work parameters to better the situations. Handling and storing raw materials like lighter material, empty bottles, wrapping papers, etc., may be integrated vertically instead of spreading horizontally to manage the space well. Similarly, the warehouse for storing finished goods may be efficiently managed. Efficient principles of shopfloor layout and facility location planning must be integrated with supply chain and logistic principles in FMCG units that specifically dwell on the success of the material movement (Myerson, 2015; Stephens, 2019).

3.4.7 Organizational ergonomics

Organizational ergonomics principles benefit organizations a lot. These FMCG units must consider these principles for their benefit. Workshift duration, job rotation, job enrichment, job enlargement, etc., might be applied in various departments, assessing the required work parameters and efficiency (Hendrick, 1991; Duffy, 1999). It will help to keep workers and managers more efficient and productive. Work training and welfare activities for temporary and unskilled workers will also prove beneficial and must not be taken as an extra burden by the management. It will help them build a reserve pool of effective workers in need and emergency (Bridger, 2017).

3.4.8 Environment monitoring

Regular and routine monitoring of existing environmental factors within an industrial unit is vital to retain the manufacturing unit healthy, safe, and congenial for carrying out ongoing work activities (Parsons, 2000; Karwowski and Marras, 2003; Karwowski, 2005; Bridger, 2017; Stack and Ostrom, 2023). The FMCG units must have their modern advanced apparatus for monitoring several environmental factors, and routine in-house audits must be carried out periodically by trained staff/ team. Specialized audits for various environmental factors may be carried out at fixed intervals by external agencies, and their suggestions must be adhered to (Murrell, 2012; Hedge, 2016). Context-specific needs of FMCG product manufacturing may be consulted and brainstormed, and innovative design interventions suitable according to distinct needs may be implemented.

3.5 Scope for Improvements: Broad Categories

As observed on the FMCG manufacturing shopfloor, several cases have been discussed in the above section for the probable root cause, previously taken approaches by various researchers in diverse industrial sectors, and potential need and requirement of implementing those in the FMCG sector. There lies a scope for improvement of shopfloor activities within the FMCG units utilizing ergonomic interventions that may be behavioral, organizational, or design-related. These can be categorized into the following broad categories.

3.5.1 Ergonomic principles and Kaizen implementation

The anthropometric and biomechanical characteristics of the working population of northeast India need to be considered while commissioning and installing the industrial setup in this part of the country. Further, while devising Kaizen activities, thorough consideration of ergonomic principles must be taken into account for their successful implementation. Evaluation of MSDs due to the original setup of workstations and implemented Kaizens should be rigorously done to assess the root causes and propose design interventions. Kaizen's thorough implementation, which considers all production, operation, safety, ergonomics, and work standardization principles, is the key to success. Fragmented approaches will continue failing to address prevailing adverse situations.

3.5.2 Work standardization as per FMCG work parameters

Imitating lean principles into FMCG manufacturing without considering its pros and cons regarding specific work parameters of the FMCG jobs is inappropriate and may create problems (Kumar et al., 2019). Identification of appropriate work standardization techniques suitable for the FMCG jobs is required. There lies a need to determine the optimum level of man-machine deployment, pacing, spatial arrangement of workstations across assembly lines, etc. In this regard, a proper understanding of FMCG work parameters is required, and proper ergonomic and work standardization tools must be identified to propose interventions for improvement.

3.5.3 Innovative tools

Peculiar work activities of the FMCG sector need thorough attention, and context-specific innovative tools are needed for such activities. These tools can ensure safety in FMCG work activities and reduce drudgery. These tools must be cost-effective and economically viable. Rework activity, housekeeping of wet, slippery floors, oven-based shrink packaging, etc., are the most peculiar activities on the FMCG shopfloors, which need immediate attention and demand design interventions based on ergonomic principles. Sincere efforts in this direction will improve the current safety concerns and help workers and management.

3.5.4 Ergonomic tools/ techniques for FMCG work domains: Summary

The ergo-audit conducted on the shopfloor of semi-automated FMCG manufacturing units revealed the prevalence of several OSH issues and bottlenecks to productivity, as discussed in the sections above. Several interventions (behavioral, organizational, or design-related, etc.) may be planned and implemented to improve the adverse scenarios. The researchers may take a rigorous approach toward providing context-specific OSH issues. However, to immediately benefit the stakeholders (workers, safety supervisors, factory management), Table 3.2 provides a ready reckoner that may be used to implement mid-level ergonomic measures on their respective shopfloors. By critically examining the FMCG sector's fundamental parameters and mapping with existing ergonomic assessment tools, Table 3.2 summarizes the ergonomic tools that could benefit ergonomic assessment in the FMCG sector by various stakeholders. Minimal training in these identified ergonomic tools may be provided to the concerned OSH personnel/ safety officers and production managers to propagate awareness and benefit from ergonomic principles on the industrial shopfloor. They can use these tools to regularly monitor ergonomic/ OSH assessment on their FMCG shopfloor.

Table 3.2: Ergonomic tools/ techniques for FMCG work domains (Summary). (Source: author)

Ergonomic Evaluation Domain	Available Ergonomic Tools	Most Suitable Ergonomic Tools for FMCG	Selection Critique	Comments
Physical Ergonomics	RULA, REBA, OWAS, NMQ, DMQ, OCRA, MFA, HAL, Borg Rating, NIOSH, Snook Tables, etc.	REBA, NMQ, OCRA, MFA, NIOSH	Whole body Involvement is predominant, lifting is prevalent	Tools need to be used in combination by a specially formed team
Cognitive Ergonomics	JSQ, WSQ, Generic NIOSH JSQ, NASA-TLX, EEG, HRV, fMRI, GSR, EDR etc.	JSQ, NASA-TLX, and any of the bio-electric potential techniques	Highly repetitive fine finger and wrist movements are predominant, and rapid hand-eye coordina-tion is required	Qualified professionals may be required for bioelectric potential measurement evaluations
Environmental Ergonomics	Measurement of Lux, DBT, WBT, WBGT, IAQ, TWA, SLM, WBV, HAV, etc.	All these measurements in combination should be taken. (simple & easy to measure)	Fine packaging needs a high illumination level, wide use of chemical compounds	Should be taken on a periodic basis regularly
Safety Issues	PHA, HAZAN, CHA, HAZOP, RA, FMEA, TOR, FTA, RCA etc.	PHA, HAZAN, CHA, HAZOP, Context-specific PPE usage	Process-based industry, wide use of industrial chemicals, e.g., menthol	Routine hazard analysis checks should be done so that accidents remain averted
Work Standardization	Takt Time improvement, MOST, MTM-1, MTM-2, MTM-3, OEE	Takt time improvement, context-specific work studies on the spatial arrangement of workers/workstatio ns, OEE	Highly paced assembly lines, work stations lie on both sides of the assembly line	Efficacy of MOST, MTM techniques may be explored in FMCG assembly line work

3.6 Prioritization of Area of Concern

Several OSH-related issues were identified from the preliminary ergo-audit conducted on the shopfloor of FMCG manufacturing units (Singh and Karmakar, 2021). Although these manufacturing units were working under varied levels of production scale, most of these identified issues remain prevalent on their shopfloor with varied intensities. These may be classified into three broad categories, as discussed in sub-section 3.5. Various mitigating solutions may be proposed to improve the prevailing adverse scenarios.

Providing solutions to all the identified OSH issues was impossible in a single research study due to different time constraints and logistics reasons. Therefore, the researcher decided to identify the most critical area of concern based on the opinions of the stakeholders. The prioritized and selected areas of concern may further be taken into account, and a suitable mitigating solution may be provided. The following subsections discuss in detail the identified OSH issues, the process followed to prioritize the critical areas of concern, and, finally, select the most critical OSH issue for which an adequate mitigating solution is proposed.

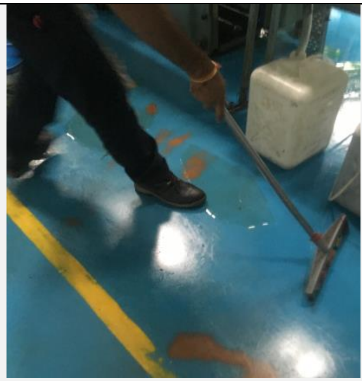
Table 3.3: OSH issues identified and prioritization done deploying card sorting technique. (Source: author)

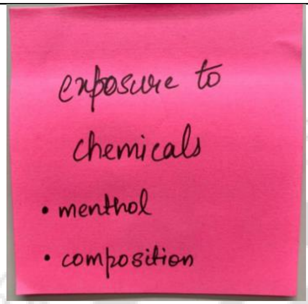
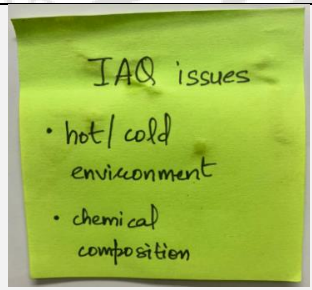
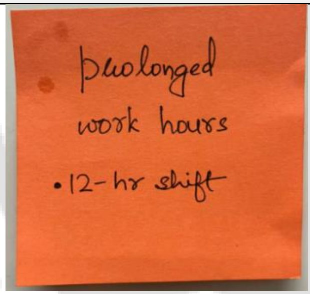
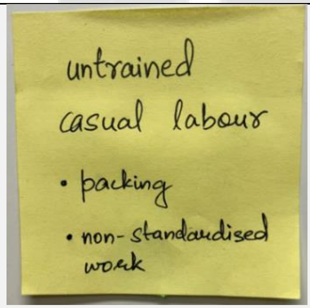
S. No.	OSH Issues Reported	Representative Case	Identified Cause	No. of Responses	Percentage (%)
1.	Awkward posture adoption		• anthropometric mismatch • inadequate workstations	35 (60)	58.3
2.	Uneasy/ uncomfortable seating arrangements		• no footrests • no lumbar support • no lateral clearance • in-house furniture	42 (60)	70.0

3.	Prolonged sitting and standing		• long work-shift duration • typically 12 hours shift	17 (60)	28.3
4.	Exposure to machine vibrations		• no lateral clearance • Kaizens forcing workers to sit colliding with accessories	09 (60)	15.0

5.	Low efficiency in the overall production process		• faulty initial and final workstations (e.g., bottle feeding and packing stations)	05 (60)	8.3
6.	Intermediate Kaizens resulting in desynchronization of the subsequent production process		• improper planning and implementation	00 (60)	0.0
7.	Non-capturing of motion economy for productivity		• non-standardized work activities	00 (60)	0.0

8.	Unorganized and congested shopfloor layout plans		• subsequent modifications to the initial shopfloor layout/ plans	06 (60)	10.0
9.	Unsafe rework of defective pouch/ sachets		• prominent use of sharp cutter blades in bare, slippery hands • manual squeezing • inadequate collection bins	54 (60)	90.0
10.	Unsafe housekeeping (sharp solid particulates mixed in liquid content)		• inadequate tools • non-availability of context-specific tools for such purpose (e.g., broken glass pieces drenched in spilled liquid)	49 (60)	81.66

11.	Slips, trips, and falls		• oil leaking and spills • improper housekeeping • inadequate tools for housekeeping	37 (60)	61.6
12.	Hot surface contacts (in packing)		• heat ovens used for shrink packaging	27 (60)	45.0
13.	Attempting unsafe acts at the workplace		• horseplay by shopfloor workers (especially by casual labor)	00 (60)	0.0

14.	Exposure to chemicals		• menthol-based manufacturing • majority of personal care products use chemical compositions	02 (60)	3.3
15.	Indoor Air Quality (IAQ) Issues		• heavy dependency on context-specific chemical compositions • hot and cold environments	03 (60)	5.0
16.	Prolonged work hours		• factory work policies	14 (60)	23.3
17.	Untrained casual labor		• factory work requirements	00 (60)	0.0

3.6.1 Methodology

Initially, all the identified OSH-related issues were documented along with the visual evidence gathered from the ergo-audit conducted. Table 3.3 above illustrates the identified OSH risks and one representative case with their probable root cause. Each case out of the seventeen prominent OSH issues identified was created into a card form (index card depicting a representative photograph or information text). The index cards were prepared for further discussion with stakeholders and to prioritize the most critical area of concern among those. The 'Card Sorting' technique is a qualitative method that helps organize and categorize the knowledge of individuals (participants) in a group or rank-order form and can be used for logically prioritizing the information required for context-specific needs (Tullis, 1985; Faiks and Hyland, 2000; Sinha and Boutelle, 2004; Wood and wood, 2008). Initially developed by psychologists in the 1980s, it is the widely used technique for quickly grouping, prioritizing, and analyzing information. It is easy to conduct and repeat, requires minimal setup cost, and has varied applicability (Spencer, 2009). Researchers have used this technique in various domains of research for grouping and prioritizing the available information as per their research context by conducting quick card sorting sessions (Lloyd et al., 2008; Li et al., 2016; Aarts et al., 2020; Navas et al., 2021).

To identify the most critical area of concern from OSH purview that must be prioritized according to the stakeholders (shopfloor workers, manager/ supervisors, and factory management), three participants from each of the twenty manufacturing units were selected on a random basis. It included at least one shopfloor worker, one line in charge/ safety in charge, and one personnel from factory management (directly dealing with shopfloor operations). These were selected per the inclusion criteria, which required that any selected participants have one year of experience in their respective manufacturing unit. Following this approach, the researchers had a respondent pool of sixty (60) total respondents from twenty manufacturing units.

In each manufacturing unit, all three selected respondents were provided with the seventeen index cards prepared (with representative case visual evidence and text information). They were asked to rank-order the given index cards as per their opinion of critical concern. The respondents need to rank-order the index card for only five ranks, i.e., 1st to 5th place. The rest of the other index cards ranking 6th to 17th place were not considered for further analysis. Considering such a selection approach (five cards as per priority/ critical concern) and having sixty respondents in all, a total of three hundred (300) responses was possible, which was quite handy and feasible for analysis in practical concern.

All three respondents from each manufacturing unit ranked the index cards depicting OSH issues as per their opinions, considering the instances of such problems prevailing on their shopfloor and their severity and need for mitigating solutions. In addition, discussion and brief interviews based on open-ended questions were conducted to discuss their choices, possible intervention modes, and anticipated/ desired qualities and functions from the probable mitigating solutions. Table 3.3 above depicts the total number of responses gathered for each OSH issue and its percentage out of all responses.

3.6.2 Observation/ results

Figure 3.8 provides the results and insights gathered from the card sorting process.

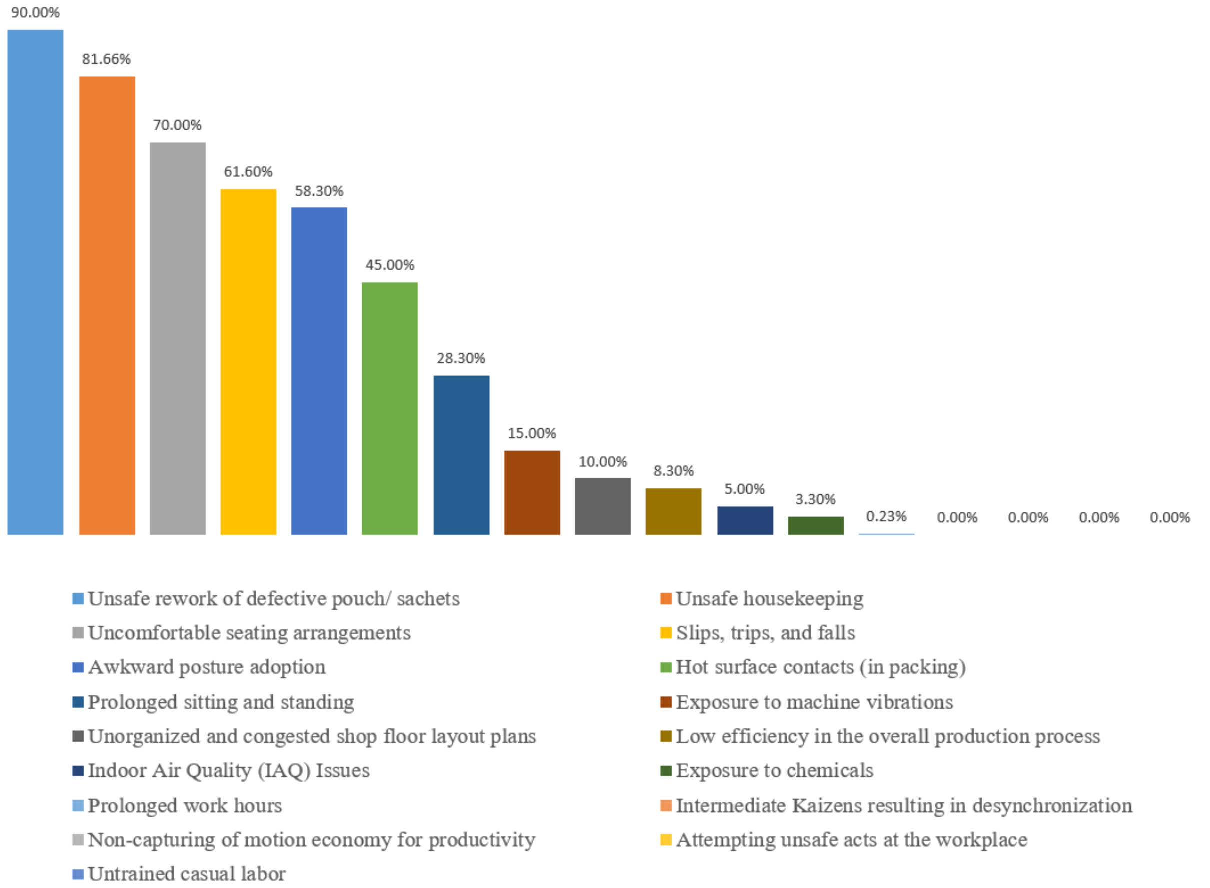


Figure 3.8: Results and insights (card sorting sessions). (Source: author)

The card sorting sessions conducted at each manufacturing unit engaging three respondents as per the selected criteria resulted in several insights that helped prioritize and choose the most critical area of concern. It was observed that the index card numbers 09 (90%), 10 (81.66%), 02 (70%), 11 (61.60%), and 01 (58.30%) were the topmost selected cards in the prioritizing rank-order grouping by the respondents. These depicted unsafe rework of the defective pouch/ sachets, unsafe housekeeping, uncomfortable seating arrangements, slips, trips and falls, and awkward posture adoption, respectively. These were the top five index cards that found a place in the top 1st to 5th places of the majority of the respondent's prioritization list. Interestingly, card number 09 was the topmost card that appeared at the 1st or 2nd place of more than 50 respondents. Very few respondents placed the card numbers 05 (8.3%), 15 (5%), and 14 (3.30%) in their top five prioritized areas of concern. Card numbers 06 (0.0%), 07 (0.0%), 13 (0.0%), and 17 (0.0%) representing intermediate Kaizens resulting in desynchronization, non-capturing of motion economy for productivity, attempting unsafe acts at the workplace, and untrained casual labor, respectively never appeared in the top five priority places of any respondents. From the above discussion, it is pertinent to note that the 'unsafe rework of the defective pouches/ sachets' was the most critical area of concern as per the stakeholders. It needs immediate attention from the researchers, and adequate mitigating solutions need to be devised to improve this non-standardized work activity prevalent in the manual and semi-automated FMCG manufacturing units.

3.6.3 Discussion

The analysis of the card sorting data revealed the unsafe rework of defective pouches/ sachets, unsafe housekeeping (engaging glass pieces and liquid), uncomfortable seating (especially in bottle filling and packing activities), and slips, trips, and falls due to wet slippery floors as the top four OSH issues. These issues are prevalent on the shopfloor of every semi-automated FMCG manufacturing unit, dependent on considerable labor engagement. These relate to the context-specific work activities performed on the FMCG shopfloor. Such work activities are very peculiar and prominent features of the FMCG sector. Rework of defective pouches/ sachets is one such non-standardized work activity that is essentially carried out on FMCG shopfloors. However, no standardized tool/ device/ apparatus exists to carry out this prominent work activity in a standardized form. The stakeholders realize the importance of this activity on their shopfloor and are concerned about the inherent safety risk it poses. According to them, mitigating solutions are essentially required to enrich safety in this peculiar work activity.

During the preliminary Ergo-audit of FMCG industries for prioritization of critical areas of concern that need immediate attention from Ergonomics and OSH perspectives, the researcher, with due consultation with the factory management and safety supervisors, brainstormed and decided that although various kinds of interventions, viz. managerial, behavioral, design, engineering, Personal Protective Equipment (PPE), etc., may be possible to execute and implement, the safety in the rework activity may be best enhanced practically through engineering and design solutions. In their opinion, the innovative design solution focused on providing tools/ apparatus for such injury-prone activity will be a boon for the FMCG sector as a whole.

Table 3.4: Desired qualities and functions of the intended design intervention. (Source: author)

Desired Qualities and Functions	
cost-effective (for a rough estimate) ▪ up to 250 USD for non-powered apparatus ▪ up to 1200 USD for powered apparatus	ample number of pouch/ sachet cutting (as per context-specific requirements)
safe to use, durable, non-spilling	splashproof, easy maintenance (in-house)
non-contaminating (rustproof)	self-drip (liquid collection)
lesser wear and tear, vibration less/ high stability	easy collection of extracted liquid
high effectiveness, unisex usage	sachet collection mechanism (empty pouches)
easy assembly, operability, and transportation	less force consumption
commercial viability (mass production)	easy operation – sitting/ standing
ergonomic posture adoption, aesthetically designed, complete workstation needed	easy working (training unskilled workers)

Further, the researcher proactively considered their opinions and enquired about their anticipations from the intended tool/ device/ apparatus. They expressed their opinion that the intended design intervention (tool/ device/ apparatus) must be capable of eliminating the need to hold a sharp cutter/ blade in bare, slippery hands and manual hand squeezing and should not affect their present working capacities. In addition, the stakeholders expressed their general opinions about the desired qualities and functions of such an intended design intervention. Table 3.4 above summarizes a few of such desired qualities and functions.

3.6.4 Finalized area of concern (rework of defective pouches/ sachets)

It is evident from the above discussion that the rework of defective pouches/ sachets that was prevalent on FMCG manufacturing shopfloors across all FMCG manufacturing units engaged in personal care goods manufacturing under varied scales of production and associated work parameters was selected as the prioritized area of concern. The design intervention in the form of a safety-enriched tool/ device/ apparatus developed as per the context-specific needs and requirements was deemed a probable mitigating solution. Therefore, it was planned to devise innovative safety-enriched tools/ apparatus of standardized form to address the safety concerns prevalent in this critical task/ activity.

3.7 Rework of Defective Pouches/ Sachets: Details

Indian FMCG sector has three main segments – food and beverages, which account for 19 percent of the industry; healthcare, which accounts for 31 percent; and household and personal care, which accounts for the remaining 50 percent (Care Rating, 2018). In contrast to the global FMCG sector, which has the food & beverage segment as the majority shareholder, the Indian FMCG sector has personal care products as the major shareholder. In the Indian scenario, most FMCG players compete in similar kinds of personal care products like hair oil, shampoos, fairness creams, cosmetic products, etc. Such personal care products are manufactured in semi-automated production setups working under varied scales of production levels. FMCG products, like hair oil, shampoo, cosmetic products, etc., are manufactured on automated assembly lines and individual pouch/ sachet filling units with provisions for high-speed filling of glass bottles, plastic bottles, and pouch/ sachets. In a single manufacturing unit, many parallel assembly lines and individual pouch/ sachet fillers work simultaneously to produce millions of such low-cost-high-volume products daily. The filled glass bottles, plastic bottles, and pouches/ sachets are packed manually. Reworking defective products, especially pouches and sachets, is a high-intensity manual task prevalent in FMCG manufacturing units. Pouch/ sachets of personal care products like hair oil, shampoo, etc. are manufactured in large numbers daily and often contain in-filled liquid content varying from 1ml to 5ml content (up to 10ml, in case some festive offer packages are manufactured). In such pouches/ sachets, the infilled liquid content is filled in a plastic envelope that is sealed from both ends, and the outer envelope bears the print details like the company logo, batch number, manufacturing details, price, license details, etc. These details are essential for the proper dispatch, sale, and marketing of such pouches/ sachets. These pouches/ sachets are manufactured in long strips (Figure 3.9), typically having 120 to 200 pouches/ sachets in a single bunch (typically consisting of multiple strips of the order 10*12, 10*20, 12*12, 14*12, etc.) depending upon the in-filled liquid contents. Figure 3.9 illustrates one such bunch consisting of multiple pouch/ sachet strips.

Figure 3.9: A single bunch of pouches/ sachets (containing multiple strips). (Source: author)

Often while manufacturing such bunches of sachets/ pouches on high-speed filling-based individual pouch/ sachet filling units, the finished pouches are rejected during the quality checks due to various quality reasons like non-printing of proper batch numbers (label graphic details), inappropriate price marking details, inappropriate manufacturing date marking, inadequately filled quantity, shrinkage of pouches/ sachets (due to overheating/ vibrating machines), improper cutting (as per standards), etc. In such cases, only the outer part of the pouches/ sachets (the envelope containing label graphics details) is considered waste (defective), whereas the in-filled liquid content (oil/ shampoo) remains good and needs to be recovered for fresh-filling in new pouches/ sachets. Such extraction/ recovery of the in-filled liquid contents from the defective outer envelopes is a non-standardized work activity carried out manually and is better known as rework activity.

Since FMCG products are low-cost, high-volume products manufactured in bulk utilizing mass manufacturing processes on multiple high-speed assembly lines, individual filling units, etc., these are produced in several million such products daily. Typically, in a small-scale manufacturing unit having 2-3 individual pouch/ sachet filling units, an average of 0.5- 08 million such small pouches/ sachets are manufactured daily. Simultaneously, the number of rejected (defective) pouches/ sachets ranges to 0.1 million pieces daily. This high rate of faulty pouches/ sachets occurs as if even one or two pouches/ sachets go wrong (defective) within the bunch (consisting of 120 - 200 pouches/ sachets), the whole bunch is rejected and sent for rework. Therefore, reworking defective pouches/ sachets within the FMCG manufacturing units is a voluminous and prominent activity of non-standardized form.

Rework of defective pouches/ sachets is a non-standardized work activity that is tedious and often prone to several safety-related issues. The pouch/ sachet rework activity primarily comprises defective outer envelope cutting activities that are often carried out using sharp-edged blades/ cutters and scissors used with bare, slippery hands, as depicted in Figures 3.10 and 3.11, causing cuts and injuries and becomes a safety concern for the workers and factory management. Once the outer envelope is cut open, forceful manual hand squeezing is required to squeeze the in-filled liquid content that often spoils the workers' hands and may contaminate the liquid content. The extracted liquid is further collected within inadequate collection bins that are readily available off-the-shelf plastic bins using a fine sieve on the top used as a filter (refer to Figures 3.10 and 3.11). No standard or innovative context-specific tools/ apparatus exists to carry out this essential activity on the FMCG shopfloor with ergonomic and safety considerations. It is carried out on FMCG shopfloors using varied work postures, sometimes while sitting and often standing, depending upon the available infrastructure and adopted work methodologies. Such rework activities are prevalent on every FMCG shopfloor engaged in manufacturing pouch/sachet-based products, irrespective of their scale of production levels. Considering the importance and severity of the safety concerns in FMCG rework activities, there lies an immediate need to provide mitigating solutions practically in the form of innovative tools/ apparatus as ascertained during ergo-audit and subsequent prioritization of the critical area of concern with the stakeholders. Such tools/ apparatus could help address the existing safety issues, promote safety, reduce drudgery, and promote the workers' well-being in rework activities.

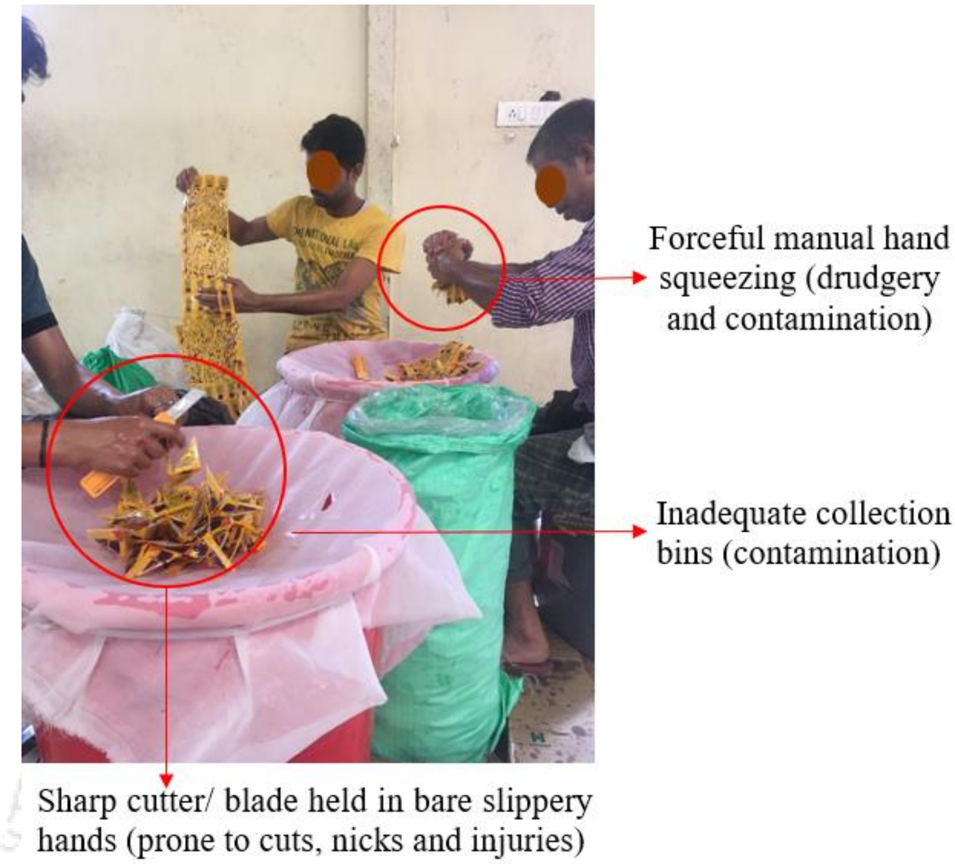


Figure 3.10: Rework of defective pouches/ sachets in a sitting position. (Source: author)

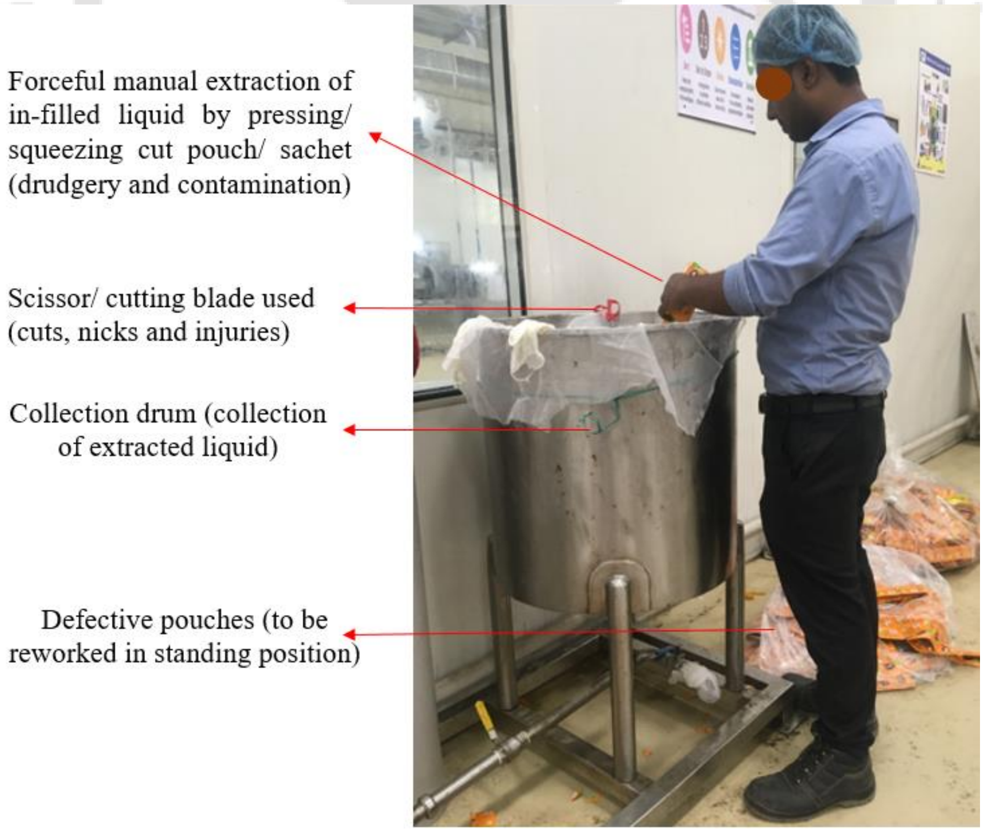


Figure 3.11: Rework of defective pouches/ sachets in a standing position. (Source: author)

3.8 Approaching the Prioritized Area of Concern

As discussed in the previous subsections, the rework activity of defective pouches/ sachets was chosen as the critical area of concern. Innovative design interventions were deemed a perfect choice for providing appropriate context-specific mitigating solutions. Earlier, it was observed during the ergo-audit that the non-standardized work activity was prevalent in all FMCG manufacturing units irrespective of their scale of production and proportionally associated rework. It is performed in varied styles utilizing varied postures dependent on available infrastructure and production-related needs and requirements. The current research takes into consideration the personal care products manufacturing units that are working under varied levels (mega, large, SME); however, their production processes remain manual and semi-automated. As already discussed, the standard activities of mixing and preparation of chemical compositions, bottle filling (glass or plastic), pouch/ sachet filling, etc., remain dependent on automated machine parts (machinery, assembly line, individual machine units, etc.); however, the high labor force is involved in its packing, rework, housekeeping, dispatching, and various other context-specific jobs/ activities. For such manual and semi-automated production process-based industries, it can be ascertained that the overall number of employees on the shopfloor directly corresponds to the production scale. For example, following the field visits, it was noticed that the manufacturing units working under mega projects were employing a large labor force to carry out their routine processes, and the corresponding scale of production was high. The rework of defective pouches/ sachets was directly proportional to the level of scale of production. All these twenty FMCG manufacturing units can be broadly classified into three distinct scales of production levels: small-scale production level units, mid-scale production level units, and high-scale production level units. Their needs towards the rework activities vary depending on their production levels, the nature of workers involved, work parameters, infrastructure available, product cost, work postures, etc.

Therefore, considering all these varying parameters depending on the production scale, it was assumed that probably a single tool/ apparatus may not be capable of satisfying the exact needs and requirements of all such manufacturing units. Probably, there is a need to further explore their context-specific needs and design and develop mitigating solutions accordingly. It was decided to select one representative factory unit each from the small-scale production level, mid-scale production level, and high-scale production level units to achieve this goal.

The following subsection provides detailed information on selecting such industries and associated parameters.

3.8.1 Selection of three levels of industries

The safety-enrichment of pouch/ sachet rework activity was chosen as the prioritized concern following ergo-audit and subsequent interviews and discussions with the stakeholders. Rework activity was prevalent on all the FMCG shopfloors irrespective of production scale, employee engagement, capital investment, cost of production, etc. It was probably anticipated that the intended mitigating design solution would probably be dictated/ governed/ constrained by the scale of production, cost, and available resources. Therefore, it was projected that different levels of innovative design solutions would be needed to cater to the needs of varying levels of FMCG manufacturing units working under varying scales of production.

To move forward in this direction, foremost, the three different FMCG manufacturing units (industries) working under three different levels of production scale were chosen. These were the representatives of each category of production scale. Brief demographic details of those industries are presented in the following tables (Tables 3.5, 3.6, and 3.7). For anonymity's sake (to adhere and comply with the executed NDA terms and conditions), these manufacturing units (factories) are named Factory A, B, and C, respectively.

Table 3.5: Factories selected (investment and employment details). (Source: author)

Name of Unit	No. of Units in Assam	Investment (Crores)	Employment (Workers)	Type of Project
Factory A	01	7.5	180	MSME
Factory B	02	22	425	Large
Factory C	03	325	1270	Mega

Table 3.6: Factories selected (work pattern-related aspects details). (Source: author)

Name of Unit	No. of Shifts	Duration of Shift (Hours)	Daily Production (Hours)	Employment (Workers)		Type of Labor Organization
				Permanent	Contract	
Factory A	02	12	24	180	100/150 daily	No union
Factory B	02	12	24	425	70/100 daily	No union
Factory C	03	08	24	1270	200/250 daily	Labor union

Table 3.7: Factories selected (production-related aspects details). (Source: author)

Name of Unit	Workstations					Production Shopfloor Arrangement
	Mixing/ Filling	Bottle Feeding	Packing	Dispatching	Rework	
Factory A	Automatic	Manual	Manual	Manual	Manual	Horizontal single floor
Factory B	Automatic	Fully Automatic	Manual/ Automatic	Manual/ Automatic	Manual	Vertical 03 storied unit
Factory C	Automatic	Manual	Manual	Manual	Manual	Vertical 02 storied unit

Factory A was working under small-scale production levels and engaged less than 400 employees, including casual labor. Rework activity in this unit was carried out manually. Factory B, the representative of mid-scale production units, employed a combined workforce of above 400 but less than 1000 employees to produce personal care goods. Employing more than 1000 workers, Factory C remained engaged in large-scale production.

The design and development of innovative design interventions (in the form of safety-enriched pouch/ sachet cutter) were planned for these Factory units. Rigorous explorations of the rework activity and its associated parameters were further studied in detail, and their context-specific needs from the intended innovative tool were assessed. A systematic product design and development process was implemented to devise context-specific tools/ apparatus for safety enrichment in FMCG rework. The detailed design and development process is discussed in upcoming chapters 4, 5, and 6.

3.9 Conclusion

The Indian FMCG manufacturing units engaged in personal care products are generally semi-automated and rely on a large labor force to carry out their routine jobs. Several non-standardized work practices peculiar to FMCG work remain prevalent on their shopfloors. Semi-automated FMCG shopfloors possess various ergonomic stressors and OSH-related issues. An ergo-audit conducted on FMCG manufacturing units revealed many such OSH issues. The most critical area of concern was selected in consultation with various stakeholders from these manufacturing units. Rework activity of defective pouches/ sachets was identified as the most critical area of concern, and design-related interventions were sought as preferable mitigating solutions to improve the existing situations. While conducting the ergo-audit, it was observed that rework activity was prevalent on the FMCG shopfloor of manufacturing units working under varied levels of scale of production. Their production level, work parameters, work demands, and labor engagement differed significantly. Therefore, it was inferred that probably a single innovative tool (same mitigating solution) may not be feasible for the needs and requirements of all such manufacturing units. Three manufacturing units named Factory A, B, and C, operating under varied scales of production, were chosen for further investigation and subsequent mitigation solution development. These were the representatives of small-scale, mid-scale, and large-scale production level units, respectively. Innovative product development (per the context-specific needs and requirements of selected units) was undertaken by deploying a systematic product design approach, presented in upcoming chapters (Chapters 4, 5, and 6).

4

Development of Pouch/ Sachet Cutter for FMCG Factory with Small-scale Production Levels

Abstract

This chapter discusses in detail the design and development process of the innovative pouch/ sachet cutter for the safety enrichment of rework jobs/ activities on the FMCG shopfloor of a factory working at a small-scale production level (Factory A). Initially, minute observations of the rework activity were made to understand the work requirements, work posture adopted, existing work scenarios, and OSH concerns. The specific needs and requirements of the stakeholders (from the intended tool/ apparatus) were gathered through discussions. Multiple concepts of the intended tool/ apparatus were generated using a Morphological chart. Ten concepts were developed. Concept screening utilizing the various criteria finalized (based on user requirements) was done using a Pugh chart. Post-concept screening, the CAD model of the selected concept was developed to explain its operational mechanism to stakeholders. The finalized CAD model was achieved after several iterations, and a physical prototype was developed. A thorough consideration of anthropometric and biomechanical parameters was taken care of while developing the prototype. The apparatus developed was put into factory trials wherein it was evaluated for improvement of productivity and ensuring user compatibility from human factors' perspectives (physical exertion in terms of increased HR, reduction of handgrip strength, cognitive workload, etc.). Following the factory trials, the developed apparatus was found effective in mitigating safety concerns and various ergonomic stressors associated with FMCG rework at Factory A's shopfloor.

4.1 Introduction

Fast Moving Consumer Goods (FMCG) manufacturing units (factories) working in semi-automated setups are often prone to several OSH-related risks due to various ergonomic stressors and non-standard jobs/ activities prevailing on their shopfloors (Singh and Karmakar 2022, 2023). Many such OSH issues were previously discussed in Chapter 3. Among them, the rework of the defective pouch/ sachet activity was selected as the prime concern that needs immediate attention from the researchers to provide an ergonomic design intervention to improve the situation thereof. It was also observed that this rework activity was prevalent on all the FMCG shopfloors, irrespective of the scale of production, employee engagement, capital investment, cost of production, etc. It is a voluminous activity often carried out with sharp cutters/ blades used with bare, slippery hands and is prone to cuts/ injuries and minor accidents. As discussed earlier, an innovative design intervention as a mitigating solution was deemed necessary, and it was noted that since the scale of production, employee engagement, capital investment, cost of production, etc., differs among the FMCG manufacturing units, a single solution (innovative design intervention) may not be able to cater to the distinct needs of the factory setup. A context-specific design intervention that perfectly suits the particular needs/ requirements of the factory setup will be a probable solution and a successful intervention. For this, three different factories working under different scales of production and having different employee engagement were selected (refer to Chapter 3).

4.1.1 'Factory A': FMCG factory with small-scale production level

A factory unit located in Guwahati city engaged in manufacturing personal care products (hair oil, serum, cosmetics, etc.) working under a semi-automated production setup was selected for further rigorous research and for proposing an innovative design intervention for the rework activity of that factory. Its production setup closely relates to the Micro, Small, and Medium Enterprises (MSME) production features, viz., low capital investment, small-scale production levels, and lesser automation. Since the researcher had an NDA with the factory management, this factory unit, for anonymity's sake, is termed 'Factory A' in the subsequent sub-sections.

The selected Factory A was manufacturing hair oil, filling the manufactured hair oil in both bottles and pouches/ sachets. The majority of its manufactured hair oil was filled in pouches/ sachets. Factory A had a worker strength of less than 400 employees. A few were regular employees, and others were contractual/ casual laborers. Regular shopfloor visits, five days a week for two months, were conducted in the initial phase to understand the demographic details of workers engaged, work elements of the job under consideration, workstation features and details (existing scenario), productivity and efficiency (existing scenario), posture evaluation, associated safety concerns and their occurrence. Rework activity was observed minutely to understand the peculiar work parameters to assess the essential function and subsequent sub-functions involved in this activity. It primarily involved cutting the defective pouch/ sachet and then squeezing the cut pouch/ sachet to retrieve the infilled liquid. Parallelly, the discussion and interviews with the various stakeholders (factory manager/ safety in charge, production supervisor, workers, etc.) were held to have their response towards the existing rework activity, the associated risk perception, their needs/ requirements, etc. All this information fetched from the initial survey was of utmost necessity to move further with the design and development of the innovative design intervention to enrich and ensure safety within the rework activity. It is discussed in detail in the subsequent subsections.

4.1.2 Insights from the survey/ field observations

The rigorous field observations of the rework activity being carried out on Factory A's shopfloor revealed several insights related to production setup, work demand, risk factors, essential functions/ subfunctions to be performed, context-specific needs/ requirements from the intended innovative design intervention, etc. These are summarized below:

4.1.2.1 Production level, work process, and urge for innovative solution

Working under an MSME production setup, Factory A usually engages contractual labor for rework. Typically, three/ four workers are exclusively involved in this non-standardized work activity daily and remain engaged in recovering the in-filled liquid content out of the defective pouch/ sachet that needs to be re-filled afresh in the new pouch/ sachets. They remain busy in their work for the shift of twelve hours, out of which their work extends for seven to eight hours. They work while sitting and cut the defective pouch/ sachets by taking the long strips of the pouch/ sachet in their hand and folding them to cut several pouches/ sachets at an instance (usually five or six pouches/ sachets). Cutting of the pouch/ sachet is done with the help of a sharp cutter/ blade that is often held with bare, slippery hands. Once the adequate number of pouches/ sachets are cut, the workers then squeeze those with their hands to extract the in-filled liquid within the temporary containers/ bins. This hand-squeezing spoils their hands with liquid content, and their hands often remain drenched with the hair oil. Once it is done, they then take the next strips to repeat the cutting and squeezing task, which continues for the whole day. On an average, they rework nearly 0.1 million defective pouches/ sachets daily at the varied rates of rework done. Their efficiency varies per hour, depending upon the cutter/ blade condition. When the blade is sharp, they tend to cut a higher number of pouches/ sachets. Once the blade gets blunt, the number of cut pouches/ sachets drops. Since their hand gets spoiled with liquid content and become slippery, it is difficult to hold the cutter/ blade; they tend to work slowly and with caution and intermittently wipe out their hand with the rough clothes kept side for wiping purposes. Although the workers try to work with caution and safety, the inherent risk associated with the sharp cutter/ blade held in bare, slippery hands often leads to nicks, cuts, and minor injuries that hamper their work efficiency. Minor cuts and injuries on a routine basis are a regular feature of this job/ task, and factory management is concerned about that and seeks an efficient solution. However, as this task is a non-standardized work activity, no Original Equipment Manufacturer (OEM) provides a standard tool/ apparatus/ device for this activity. Since factory management remains busy running day-to-day affairs, they find little time to address the safety concerns from a thorough research standpoint. Their attempts resort to in-house solutions developed under regular improvement activities (Kaizens). These Kaizens often lack thorough research orientation and ergonomic considerations and fail to improve the existing work activity and benefit the workers engaged. Management is also concerned with manual squeezing (hand-squeezing), sees it as a source of contamination, and wants to eliminate it to any level they can achieve. In the purview of these difficulties and problems associated with the rework activity, the factory manager, safety supervisors, production engineers, etc., are all eager to have mitigating solutions for this utmost essential task being performed on their shopfloors on a daily basis. For this, they seek help from the researchers to address the existing adverse situation and propose innovative design interventions in the form of context-specific tools/ apparatus that may improve the situation.

4.1.2.2 Need/ requirements from the intended solution

The researcher understood the rework activity's importance and severity and then decided to design and develop the context-specific innovative design solution in the form of a tool/ apparatus. Such an intended design solution needs to be based on thorough ergonomic and design principles that will help carry on this activity on the Factory A shopfloor with enhanced safety and productivity. Foremost, by means of discussions/ interviews, the specific characteristics (desired needs) of the intended innovative safety-enriched tool/ apparatus for Factory A were assessed. These are listed below:

- It should be manually operated (hand-held)
- It may be capable of cutting 5 - 10 pouches at a time (cutting a small number of pouches)
- The majority of its components would be in-house made or may be purchased from the local market

4.2 Development of Pouch/ Sachet Cutter for FMCG Factory with Small-scale Production Levels

This section describes in detail the design and development process followed for the development of context-specific safety-enriched tools for the safe reworking of the pouches/ sachets on the Factory A shopfloor.

4.2.1 Aim

To design and develop a safety-enriched hand-held pouch/ sachet cutter for rework activity performed in a factory with a small-scale production level. Such a pouch/ sachet cutter must be capable enough to cut 5-10 pouches/ sachets at a time and eliminate the need to hold a sharp cutter/ blade in bare, slippery hands and hand squeezing.

4.2.2 Product design and development process

To carry on the current research and proceed toward fulfilling the aim of the current chapter, a design and development process engaging various ergonomic and design principles was followed and is presented in detail in the following subsections.

4.2.2.1 Generic product development process

Generally, a product development process is a set of several systematically performed activities deployed to conceptualize, design, and commercialize a new product (Ulrich and Eppinger, 2016; Verma and Karmakar, 2021). It generally consists of two broad phases: 'ideation' (consisting of customer need identification, concept generation, and concept selection) and 'prototyping' (composed of detailed design, prototype testing, refinement, and final production). Figure 4.1 illustrates the generic process of product development.

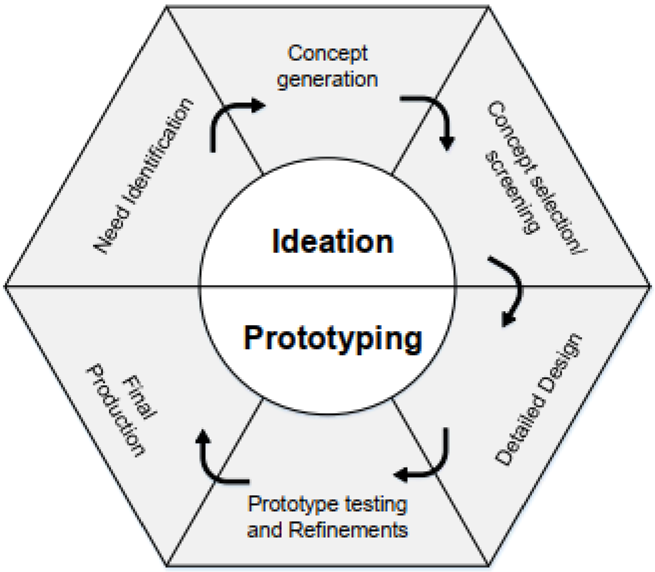


Figure 4.1: Generic product design process (adapted from Ulrich and Eppinger, 2016)

(Source: Verma and Karmakar, 2021)

The present research has deployed a product design approach to develop an innovative pouch/ sachet cutter for rework activity for the small-scale FMCG shopfloor. The activities performed in this journey are discussed in detail in the following sub-sections.

4.2.3 Product development process adopted in current research

The current research adopted the product design approach based on well-thought-out design and ergonomics principles. It was broadly conducted in three phases, viz. 1) Field Survey Phase, 2) Concept Development & Prototyping Phase, and 3) Field Trials. It employed several Human Factors (HF)/ ergonomic principles, and a summary of those adopted during the initial phase (field survey phase) is provided below:

4.2.3.1 Field survey phase

Initially, the minute survey of the rework activity was conducted to identify context-specific needs and requirements. It was done using field observations, interviews, and discussions held with stakeholders (workers, safety in charge, shopfloor managers, etc.) that comprised several questions pertaining to demographic details of workers engaged, work elements of the job under consideration, workstation features and details (existing scenario), productivity, and efficiency (existing scenario). These provided insights about the criticality of the job/ task under consideration.

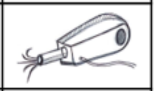
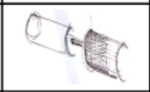
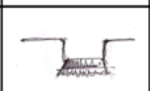
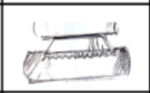
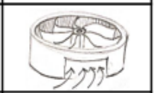
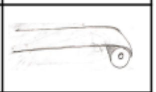
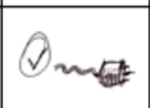
Further, Factory A's specific needs and requirements (from the intended tool/ apparatus) were also assessed to develop the innovative tool. The design limit selection (constraints) was also well thought out in this phase. It was accomplished using interviews and discussions conducted with all stakeholders. It helped understand and determine several vital parameters, viz. intended product dimensions (shape, size, product architecture, etc.), operational aspects (mechanized/ non-mechanized/ powered/ non-powered, etc.), sustainability features and issues (in terms of economic and ecological sustainability like economic viability, environmental sustainability, market sustainability, social sustainability). A careful prior assessment of other manufacturing and marketing-related aspects was also explored, and it focused on the feasibility and enablement of the product from the manufacturing aspect, manufacturability features (production strategies like mass production, etc.), intended inventory management, and logistics (compactness and packing considerations).

The current design and development process's first phase (preliminary ergo-audit) has been discussed in detail in the previous chapter (Chapter 3) through its sections and subsections. A detailed description of the second and third phases is presented in the upcoming subsections.

4.2.4 Concept generation

A well-structured approach for concept generation utilizing a Morphological chart (Norris, 1963; Verma and Karmakar, 2021; Singh and Karmakar, 2024) was followed to steer the research forward and move along with phase two of the current study. For finalizing various sub-functions of the intended product/ tool, the insights from the factory visits and user (workers, safety managers, management) requirements were given due consideration. A Morphological chart (Table 4.1) was used to generate the alternate concepts of the intended product.

Table 4.1: Morphological chart generated for pouch/ sachet concept generation. (Source: author)

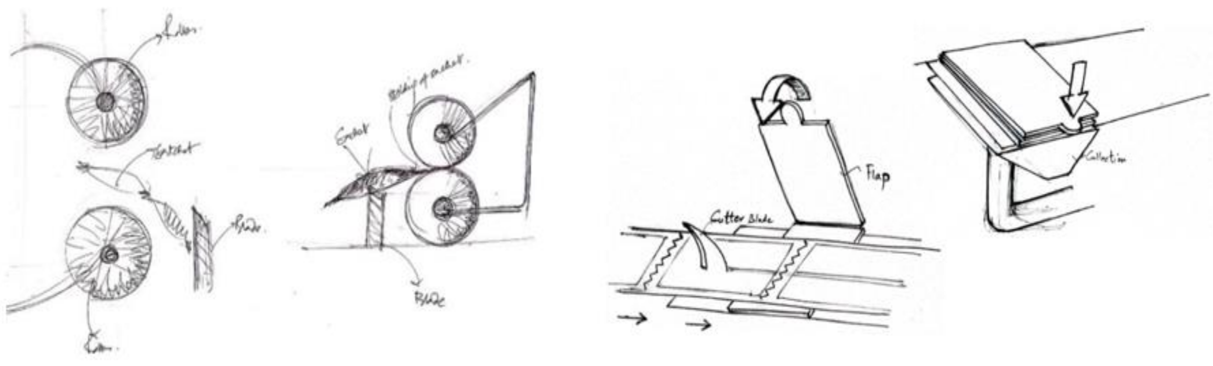
Sub Function \ Solution		Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Cutting pouch to extract liquid	1	 Surface Cutting	 Pricking	 Puncture	 Scissor	 Rotating Blade	 Spikes
Extracting complete liquid out of cut pouch	2	 Funnel Sucking	 Roller Pressing	 Wheel Pressing	 Tapping	 Block Pressing	 Suction
Moving/ holding / supporting the apparatus	3	 Body Frame	 Vertical Frame	 Between Rollers	 Flap Press	 Stick/ Plunger	 Manual Drag/ Belt
Placing the uncut pouches	4	 Guide Rail Bin	 Teeth Friction	 Drum Top	 Direct Rubbing	 Hand Held/ Belt	 Cavity
Collecting the extracted liquid	5	 Solid Drum Pipe	 Nozzle Dripping	 Direct Pipe	 Bucket/ Tub/ Bin	 Contact Transfer	 Funnel
Feeding the incoming pouches	6	 Roller Sucking	 Spike Hitting	 Rolling Gun	 Guide Rail Feed	 Manual Push	 Belt/ Flat Surface
Providing energy for apparatus action	7	 3 Phase Power	 DC Power	 Manual Effort	 Electro-mechanical		

As evident from the Morphological chart (Table 4.1) for the current product/ tool under consideration, seven sub-functions were considered: 1) cutting pouch to extract liquid, 2) extracting complete liquid out of the cut pouch, 3) moving or holding or supporting the apparatus, 4) placing the uncut pouches, 5) collecting the extracted liquid, 6) feeding the incoming pouches, and 7) energy source for apparatus action. To fulfill these sub-functions, different options had to be accessible. The options available for each sub-function were then identified and recognized as sub-components. Based on these, a Morphological chart (Table 4.1) was developed depicting various sub-functions and options available to perform that sub-function. It was created for ideating the multiple concepts of the 'pouch/ sachet cutter.' Based on inputs from the Morphological chart, ten concepts were generated using an amalgamation matrix (Table 4.2) of sub-functions and sub-components of the Morphological chart.

Table 4.2: Amalgamation matrix for pouch/ sachet concept generation. (Source: author)

Concept	An amalgamation of a matrix for conceptual sketch
Concept Sketch 1	(1,1) + (2,3) + (3,3) + (4,4) + (5,5) + (6,3) + (7,3)
Concept Sketch 2	(1,1) + (2,5) + (3,4) + (4,1) + (5,6) + (6,5) + (7,3)
Concept Sketch 3	(1,2) + (2,5) + (3,4) + (4,1) + (5,1) + (6,4) + (7,3)
Concept Sketch 4	(1,3) + (2,2) + (3,3) + (4,5) + (5,6) + (6,1) + (7,3)
Concept Sketch 5	(1,1) + (2,4) + (3,6) + (4,1) + (5,2) + (6,1) + (7,3)
Concept Sketch 6	(1,1) + (2,3) + (3,6) + (4,6) + (5,6) + (6,5) + (7,3)
Concept Sketch 7	(1,1) + (2,5) + (3,4) + (4,1) + (5,1) + (6,5) + (7,3)
Concept Sketch 8	(1,3) + (2,2) + (3,1) + (4,1) + (5,2) + (6,4) + (7,3)
Concept Sketch 9	(1,2) + (2,6) + (3,6) + (4,5) + (5,5) + (6,5) + (7,3)
Concept Sketch 10	(1,6) + (2,4) + (3,2) + (4,3) + (5,1) + (6,5) + (7,3)

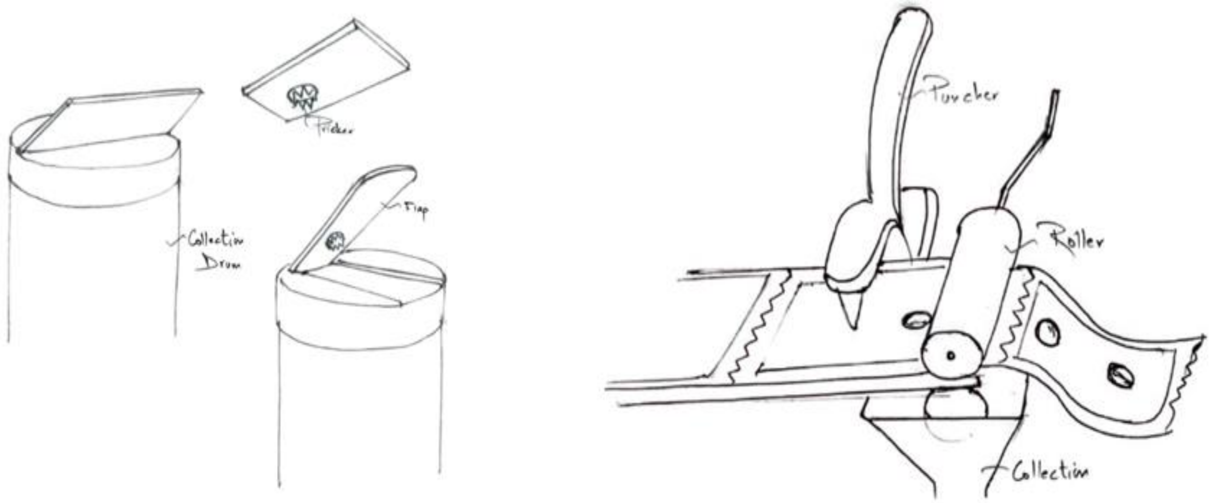
The amalgamation of different sub-components under different sub-functions to come up with the 'pouch/ sachet cutter' is shown in Table 4.2. The morphological chart and sub-components amalgamation proposed ten new concepts (Fig. 4.2 - 4.6) of the intended 'pouch/ sachet cutter.' For example, concept sketch one (concept 1) was developed by the following amalgamation: (1,1) + (2,3) + (3,3) + (4,4) + (5,5) + (6,3) + (7,3). As depicted, each concept was obtained from a combination of one option (sub-component) for each sub-function. A brief description of each concept is given below:



Concept 1 **Concept 2**

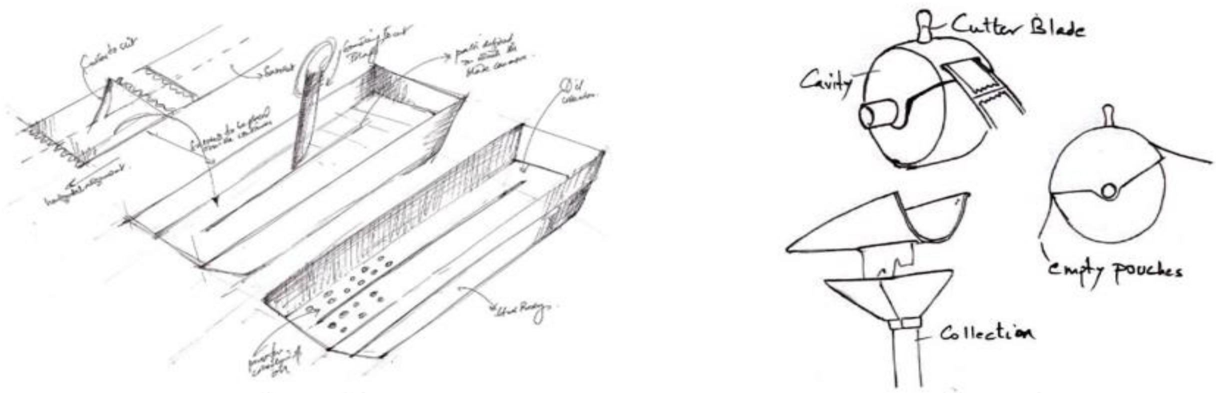
Figure 4.2: Different pouch/ sachet cutter concepts developed (concepts 1 and 2). (Source: author)

- **Concept 1:** This is a fixed-blade and roller-wheel-based concept. It has a blade fixed/ mounted upon a fixture, and the pouches/ sachets can be pulled across the cutting surface of the fixed blade that further passes through the plurality of the roller wheels that squeeze the cut pouch/ sachets to extract the liquid out. The dripping liquid content of the squeezed pouches/ sachets can be collected in an external bucket, tub, or bin. The uncut pouches may be fed through a rolling gun (coil-based) mechanism.
- **Concept 2:** In this concept, the incoming pouch/ sachet is cut via a fixed blade erected in its guideway. The defective pouch/ sachet is fed through the guideway, and the blade erected within the guideway splits the pouch/ sachet. Once the pouch is sliced, the flap is used to press the cut pouch/ sachet to extract its liquid content. The extracted liquid flows through the integrated drain pipe provided below the guideway.
- **Concept 3:** This integrated solid container (drum) based concept utilizes the pricking component embedded into the flap-based component to prick the pouch/ sachets placed in a guideway and then squeeze the liquid content through the flap-press. This concept is compact in construction and contains several components embedded within a miniature architect.
- **Concept 4:** Puncture-based, this concept punctures the incoming pouch/ sachets at the defined slot and makes a hole in the pouch/ sachet. The pouch/ sachet that got punctured (hole) further moves through the rotatable roller, and the liquid content gets extracted. The extracted liquid is collected in the main reservoir through an integrated funnel (waythrough) provided beneath the roller assembly.



Concept 3 Concept 4

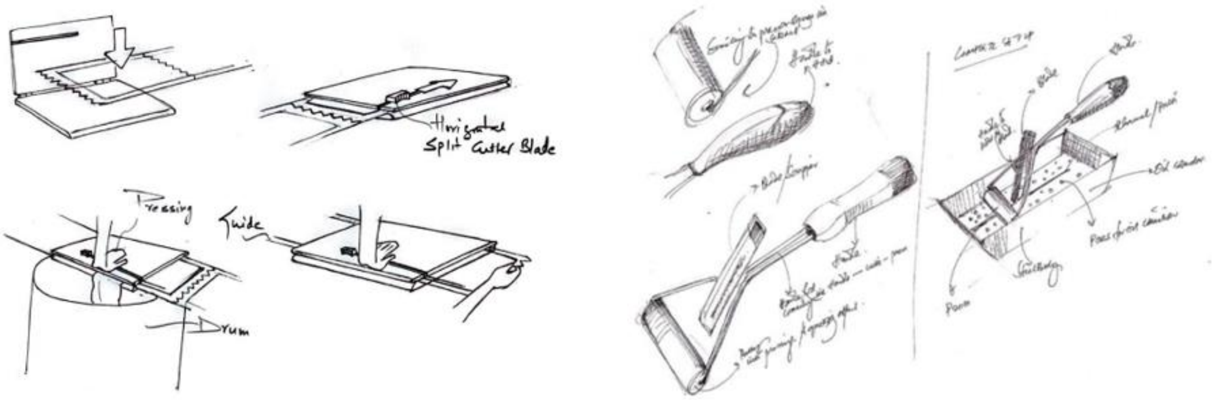
Figure 4.3: Different pouch/ sachet cutter concepts developed (concepts 3 and 4). (Source: author)



Concept 5 Concept 6

Figure 4.4: Different pouch/ sachet cutter concepts developed (concepts 5 and 6). (Source: author)

- **Concept 5:** This is an integrated container bin cum guideway-based concept. The pouch strip can be placed on the upper base of the container bin that has perforated holes and a horizontal slit (guide channel for blade). The tip of the blade/ cutter can be moved through this slit that cuts the incoming pouch/ sachets. A separate tapping block can then be placed on the cut pouch/ sachet to extract the in-filled liquid content.
- **Concept 6:** This concept utilizes a circular guideway provided with a fixed blade at its top at a designated place. The circular guideway is broad at its opening, from where the filled pouch/ sachets are fed manually, and once those are cut through a fixed blade, they pass through the narrower end and get squeezed to drain out the extracted liquid. The extracted liquid can be transferred to the main reservoir through the funnel-based tertiary container.

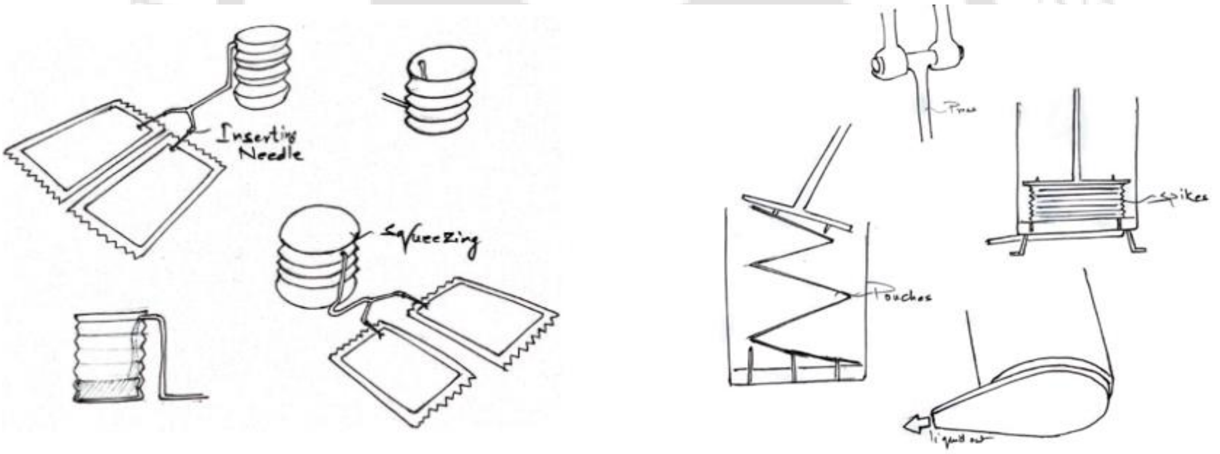


Concept 7 Concept 8

Figure 4.5: Different pouch/ sachet cutter concepts developed (concepts 7 and 8). (Source: author)

- **Concept 7:** This is an integrated solid container (drum) based concept. It utilizes the horizontally moving cutter blade integrated with the pressing flap. The pouch/ sachet strip is placed on the guideway provided on the top of the container drum, the flap containing the cutter blade is placed on it, and the cutter blade within its slot upon the closing flap is moved in the opposite direction of the incoming pouch/ sachet strip. As the pouch gets cut, the trailing flap squeezes the in-filled liquid that gets collected in its integrated container.

- **Concept 8:** It is an integrated roller-based concept. It comprises the roller fixed at the far end of the frame that contains a slot to fix the cutter blade at a fixed length/ height adjusted through the nut/ bolt mechanism. This frame containing the blade and roller can be moved within the glider cum collection bin provided separately with this frame. The pouch/ sachet strip can be fed from right to left and placed on the upper base of the container bin. The frame with the cutter is moved in the opposite direction, which cuts the pouch/ sachet strip, and the following roller squeezes the cut pouch/ sachet to extract the liquid. The extracted liquid is collected within the collection bin through perforated holes.



Concept 9 Concept 10

Figure 4.6: Different pouch/ sachet cutter concepts developed (concept 9 and 10). (Source: author)

- **Concept 9:** This concept utilizes needle insertion-based pricking and suction-based sucking to collect the in-filled liquid. It consists of a retractable vacuum-based cylinder that has a connecting pipe and the needles provided at the far end of the connecting pipe. A stack of pouches/ sachets can be placed at the designated place, and the needle can be inserted through them. Once the needle is pricked, the vacuum cylinder is pressed, that help sucks the liquid out of the pricked pouch/ sachets.
- **Concept 10:** This is a fixed spikes-based concept. Within a solid drum, vertical spikes are provided at the bottom, upon which stacks of pouches/ sachets can be placed.

Afterward, the downward-moving tapping block can pressed on it within the boundaries of the container drum. As the pouch/ sachets get punctured and pressed, the in-filled liquid gets squeezed and comes out through the bottom opening hole.

4.2.5 Concept screening

Post-concept generation lies in the critical stage of concept selection. In the product development process, the concept selection stage relates to the selection of the most appropriate concept and elimination/ screening of non-appropriate concepts as per the design objectives. Various selection/ screening criteria were finalized based on user requirements and priorities mentioned by the stakeholders (workers, safety in charge, management). Finally, the researcher chose the concept '5' as the 'DATUM' or reference. A Pugh Chart (Pugh, 1991; Lin and Hsiao, 2019; Wu and Hsiao, 2019; Von Teh et al., 2020; Singh and Karmakar, 2024) was deployed to evaluate the various concepts, and a decision matrix was prepared. Table 4.3 depicts the Pugh Chart Matrix for the current evaluation. Further, concept screening was done using the Pugh Chart (Table 4.3) to finalize the best concept among these ten concepts based on pre-defined selection criteria. As illustrated, concept number 5 was chosen as DATUM, and based on concept screening, concept number 8 was selected for further development. Eventually, it is evident from the Pugh Chart that concept '8' received the highest score of '+6' and was decided to develop further as a Computer-Aided Design (CAD) model and for subsequent physical prototype and field trials. Figure 4.7 depicts the initial concept sketches of the final selected concept. It will be taken up further for CAD model development, and the process employed is described in further sub-sections.

Table 4.3: Pugh chart for concept screening. (Source: author)

Selection Criteria	Weight	Concept Number									
		1	2	3	4	5	6	7	8	9	10
Safety in interacting with cutting mechanism	5	-	-	S	S		+	-	+	-	-
Ease of placing and feeding uncut pouches	5	-	-	-	-	D	-	-	S	-	+
Ease of extraction of in-filled liquid content	4	-	S	-	S	A	-	+	+	-	-
Ease of collection of in-filled liquid content	4	-	S	S	-	T	-	-	S	-	-
Ease of collecting/ removal of extracted pouches	3	-	-	S	S		S	-	S	-	-
Compactness	2	-	-	+	+	U	-	-	S	-	-
Low complexity (lesser number of mechanisms)	2	-	-	+	-	M	-	-	-	-	-
Cost	1	+	+	-	-		-	-	-	-	-
Weighted SUM of +		+1	+1	+4	+2	0	+5	+4	+9	0	+5
Weighted SUM of −		-25	-17	-10	-12	0	-18	-22	-3	-26	-21
Net Value		**-24**	**-16**	**-6**	**-10**	**0**	**-13**	**-18**	**+6**	**-26**	**-16**

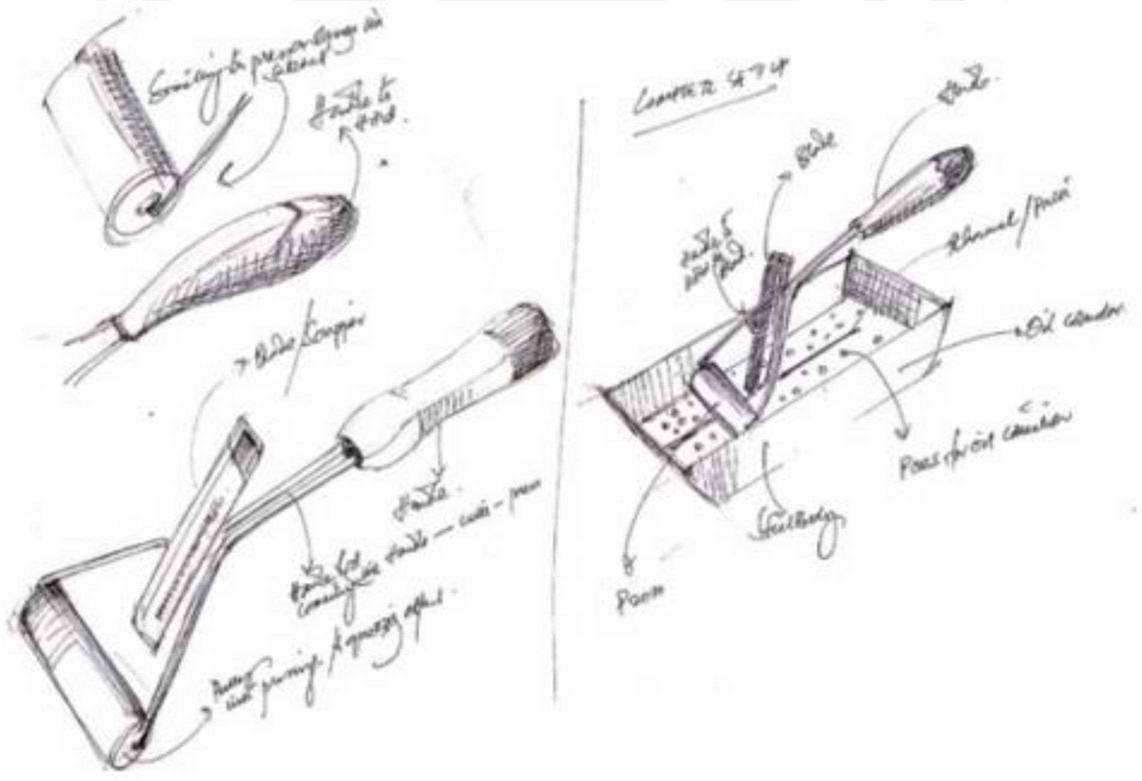


Figure 4.7: Concept selected (initial sketches). (Source: author)

4.2.6 Virtual mock-up development

Further, the CAD model for the concept '8', the best concept conceived for the intended purpose of cutting and squeezing pouches/ sachets with safety, was taken up as the next step in the present product design and development process. The initial CAD model was shown on a laptop screen to the stakeholders, and the operational mechanism was explained to get their feedback. Following their inputs, the final iterated CAD model of the intended pouch/ sachet cutter was prepared, as shown in Figure 4.8. It shows the various views of the product developed in a rendered form. The digital prototype also helped to assess the aesthetic features of the intended product (color, form, look and finish, etc.). Various human factor principles were considered while developing the final model of the product. The anthropometric and biomechanical considerations focused on hand anthropometry, wrist's range of motion, overall posture required for using the tool/ apparatus developed, dimension of developed tools according to intended posture, and corresponding workstation, etc., were primarily considered while designing the apparatus. For the development of the tool/ apparatus, the Indian Anthropometric Database (Chakrabarti, 1997) was considered. Several parameters were considered for determining product features using different population sizes/ samples from that database. Perspective views of the product developed in CAD are depicted in Figure 4.8.

Figure 4.8: Pouch/ sachet cutter (CAD model renderings). (Source: author)

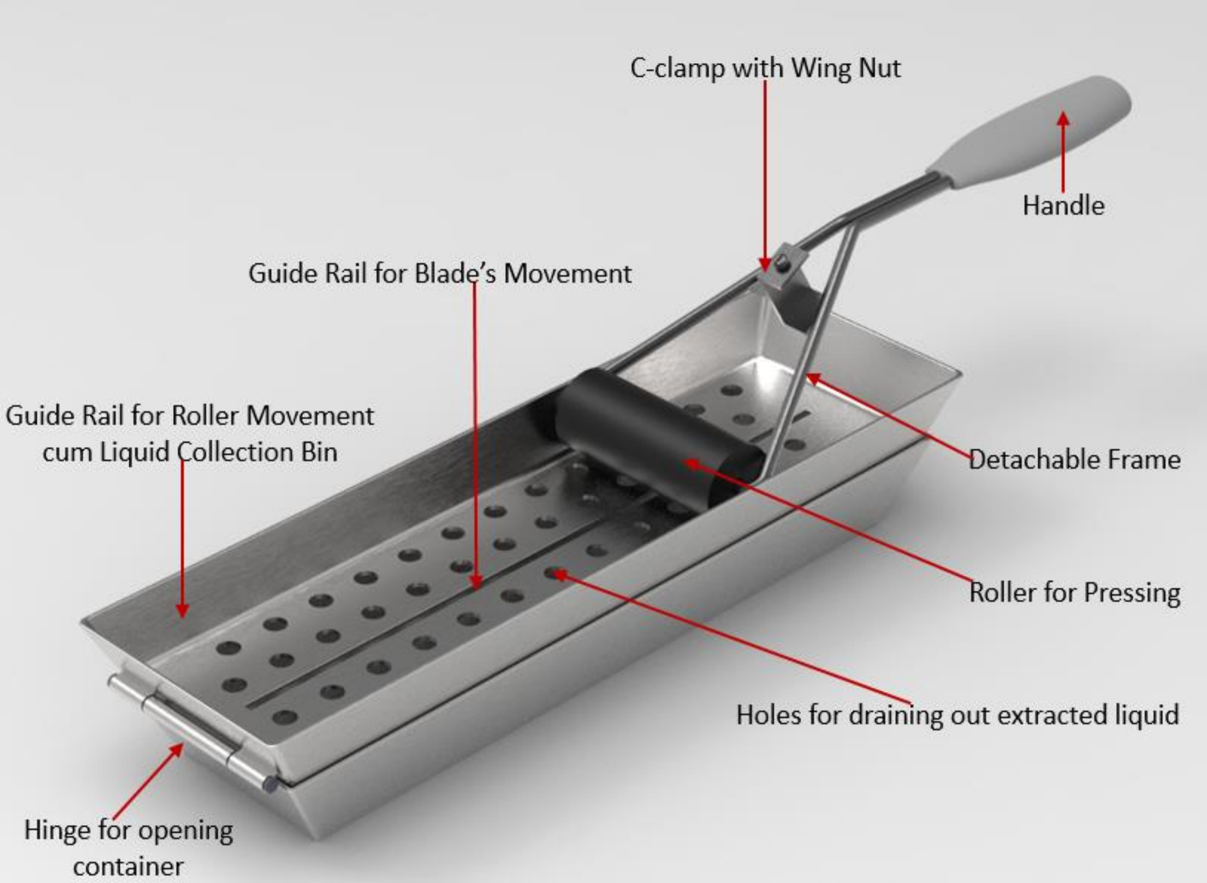


Figure 4.9: Pouch/ sachet cutter (basic part details and functions). (Source: author)

Figure 4.9 illustrates the part details of the intended product with their functioning details. Various parts of the pouch/ sachet cutter with their functions are explained to clearly understand the working/ operation of this pouch/ sachet cutter. Figure 4.10 shows the CAD model of the product developed in a wireframe form. Figure 4.11 depicts the various views of the pouch/ sachet cutter, along with their part details and basic functions. It helps to understand better the working and functioning of the product under development.

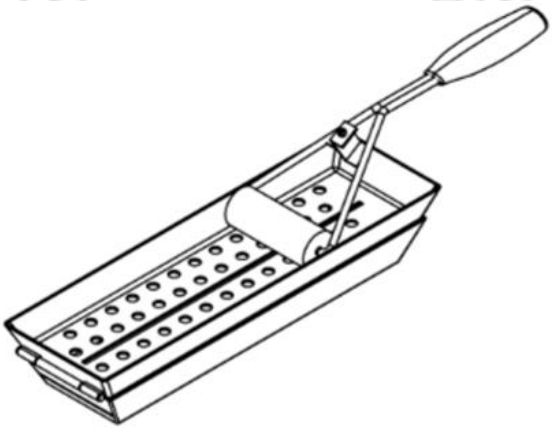


Figure 4.10: Pouch/ sachet cutter (CAD model wireframe). (Source: author)

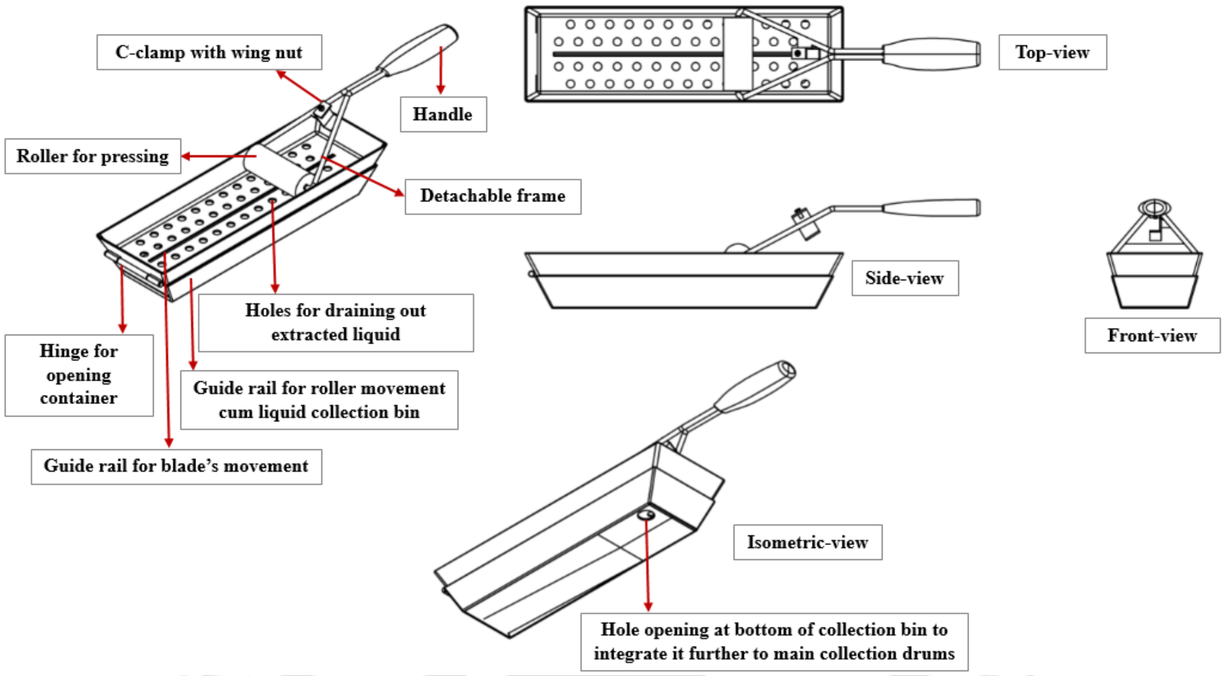


Figure 4.11: Pouch/ sachet cutter (basic part details and functions) (various views) (Source: author)

Figures 4.12 and 4.13 illustrate the essential part details of the pouch/ sachet cutter with part numbers. A brief working/ operation of the hand-held pouch/ sachet cutter (apparatus) is explained with the help of these part numbers in the following subsection.

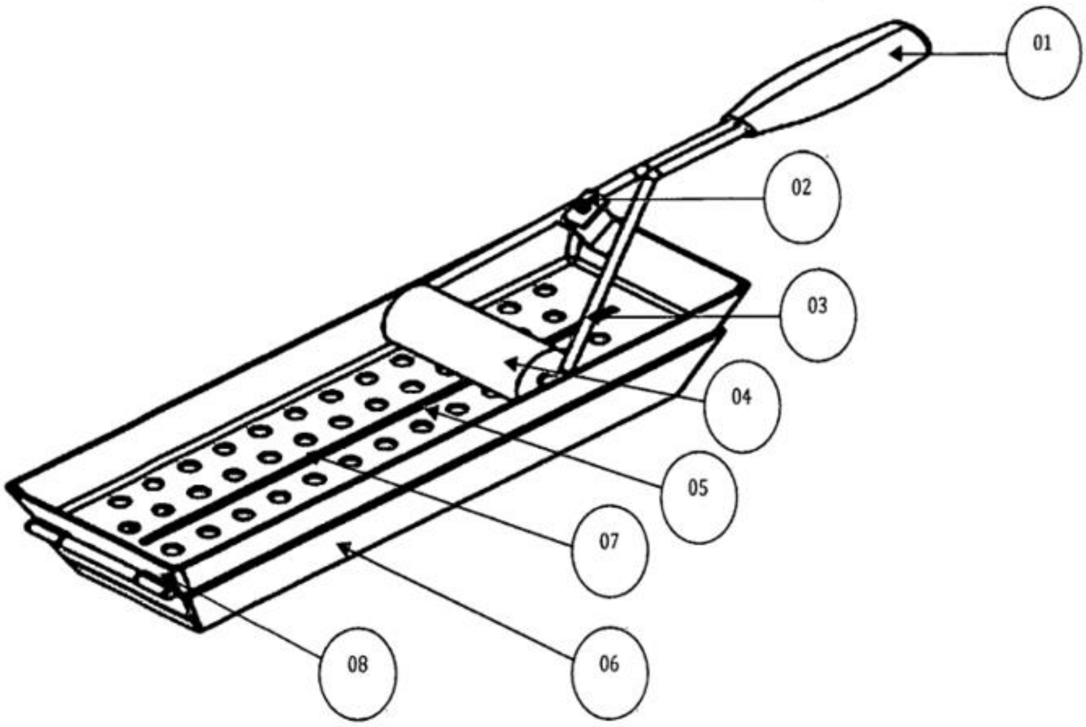


Figure 4.12: Pouch/ sachet cutter (part number and working explained). (Source: author)

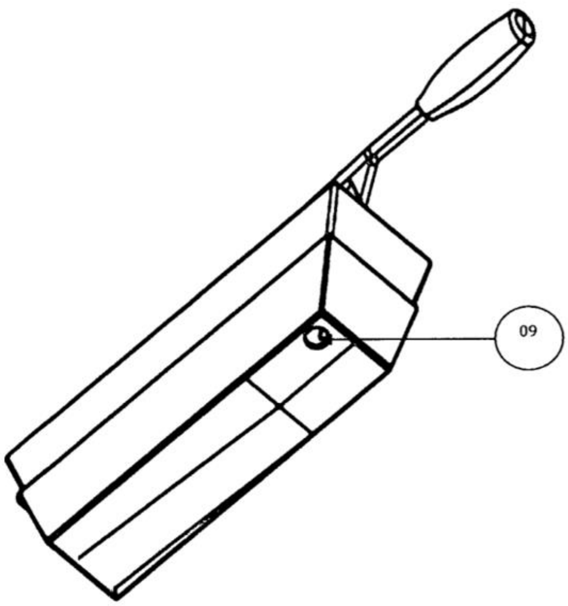


Figure 4.13: Pouch/ sachet cutter (part number and working explained). (Source: author)

In this hand-held apparatus for extracting the contents of a pouch/ sachet, the hand-held apparatus comprises:

- ✓ A roller press assembly that includes a handle (1), a detachable frame (3) coupled to the handle (1), and the detachable frame (3) being provided with a roller (4) for squeezing the contents of a pouch/ sachet; and a clamp (2) provided over the detachable frame (3), the clamp (2) being coupled to a cutter for cutting the pouch/ sachet.
- ✓ a roller glider cum collection bin being disposed below the roller press assembly, the roller glider cum collection bin includes a base for receiving the roller press assembly, the base including a plurality of holes (5) and a guide rail (7) for providing a channel for the cutter, and a collection bin (6) being provided at the bottom of the base for collecting the contents of the sachet/pouch through the plurality of holes (5).
- ✓ Hinge (8) is provided on the left side of the apparatus to open up the collection bin for cleaning purposes.
- ✓ At the bottom, the collection bin (6) includes an opening (9) for integrating the hand-held apparatus into one or more collection drums.
- ✓ This hand-held apparatus is made of stainless steel to avoid contamination of the extracted liquid.
- ✓ Moreover, in this hand-held apparatus, cutters of various lengths may be used within the frame, and the roller can be replaced, too.

In brief, from the above details and description, it can be easily understood that the present apparatus (innovative pouch/ sachet cutter) is a safety-enriched apparatus for safe extraction of the content from the damaged or defective liquid-filled pouches/ sachets in FMCG manufacturing industries. It will ensure safety in such rework activities and enhance efficiency and productivity. A strip of defective pouch/ sachet comprising 5-10 pouches can be placed/ fed horizontally on the base of the roller glider cum collection bin from the right side. The cutter/ blade attached to the frame moves on the opposite side (left to right) and cuts the placed pouches/ sachets, and the roller following the blade squeezes and extracts the in-filled liquid content out of the cut pouch/ sachets. It helps in squeezing the complete liquid, consisting of hair oil and others, out of the pierced pouch/ sachet just by pressing on its own by the moving roller over cut pouch/ sachets, thus eliminating the manual need of squeezing out the liquid by pressing and keeps the hand clean and dry as compared to the earlier situation where hand squeezing was an essential activity.

4.2.7 Physical prototype development

As mentioned in the previous section, various aspects of human factors (anthropometric, biomechanical, usability, etc.) were considered for physical product development while fabricating various components of the intended product with actual material to ensure the intended function and usability. Further, the physical prototype of the selected concept (number 8) was developed (Figure 4.14). The physical prototypes of the pouch/ sachet cutter developed are shown in Figure 4.14. The detailed drafting of this product is given in Appendix A.6 (measurements in mm).

Figure 4.14: Pouch/ sachet cutter (physical prototype developed). (Source: author)

4.2.8 Factory trials

Once the apparatus's physical prototype was ready, the field trials were carried out at Factory A to understand the product's functionality and related consequences/ insights (Figure 4.15). Ten workers were engaged for factory trials, and data regarding productivity (number of pouches cut) and other physiological/ anthro-biomechanical parameters were taken to understand the exertion levels of workers while using the developed product. Data regarding usability was also gathered. Table 4.4 summarizes testing variables (physiological and anthro-biomechanical, production, usability) (n) = 10.

Figure 4.15: Field trials at Factory A. (Source: author)

Various parameters of success may be considered/ adopted to determine the product's potential success, including performance improvements, physical/ cognitive ease, and easy adaptability. The following parameters were considered to evaluate the pouch/ sachet cutter's probable success.

4.2.8.1 Productivity evaluation

From the operational and use perspective, the product's potential success can be ascertained by its performance. The developed product, acclaimed to be an improvement of the previous version, must be capable of providing enriched/ enhanced features for various predetermined functions/ sub-functions and must not decrease the earlier reported productivity levels. The productivity levels must remain either the same or, ideally, must be increased from the previously reported productivity levels (Ulrich and Eppinger, 2016; Verma and Karmakar, 2021).

The productivity parameter for the current field trials was determined by the 'number of pouches reworked.' The number of pouches cut using the existing method (blade/ cutter and hand squeezing) and with the newly developed cutter were recorded to assess the productivity of the existing method and modified working scenario. Since there is variability among the workers' working styles, the work rate varies during the complete shift, so observing the productivity rates was tedious. So, for better judgment and accurate observation for recording purposes, it was decided to have a keen observation of the rework activity for fifteen (15 minutes) each. Three such trials were conducted at different work shift hours on the decided field trial dates. The average of the three trials was finally taken for record and reporting purposes (Table 4.4).

One major precaution was taken in the current study to fetch the best possible measurement for the determination of productivity levels using a newly developed pouch/ sachet cutter. The newly developed pouch/ sachet cutter was provided to Factory A's safety managers, and workers were advised to use those to adapt to them. It was done so that while the productivity determination in an improved context was being recorded, the productivity variation resulting from the factor of 'non-adaptability' of the new tool/ apparatus would be eliminated.

4.2.8.2 Human factors evaluation

Several human factor considerations and parameters can be adapted to determine the potential success of the newly developed tool/ apparatus. It can encompass both physiological and cognitive parameters. The following human factors were considered as parameters for such determination.

Physical exertion level

Physical exertion levels hint at and signal the physical effort, strength, and muscular stress/ strain required for performing the job/ activity under consideration. For a good and successful intervention in the form of a product/ tool, etc., it is essential that such tools/ apparatus must not require high manual effort, power, or strength and should not induce high muscular stress and strain on the worker. Heart Rate measurement/ estimation is a quick and reliable method of determining the physical exertion levels in field trials. Heart Rate estimation is important for assessing a person/ individual's physiological and pathological state (Strath et al., 2000; Marras and Karwowski, 2006b; Bridger, 2017; Song et al., 2023). The heart pumps blood around the body by beating at about 60 to 100 beats per minute (bpm). Heart rates greater than 100 bpm (Tachycardia), and those lower than 60 bpm (Bradycardia) are considered irregularities. Such Cardiac abnormalities are caused by physiological and pathological conditions that alter the normal electrical impulse that controls the heart's pumping action (Ritter et al., 2011; King and Lowery, 2017).

Heart Rate measurements in the existing scenario and improved conditions (new tool/ apparatus being used) were measured/ recorded to assess the physical exertion levels while using the earlier tool and new tool and their comparison. Heart Rates were taken for each worker at the resting state (before the start of work) and after two hours of work to have an estimate of the physical exertion being induced (by virtue of performing the rework activity) within a span of two hours. Heart Rate measurements were taken using a Polar Heart Rate monitor that was worn around the chest by male workers. However, the heart rate measurements for female workers were recorded using a Bauhn smartwatch. Prior to using these, the reliability and accuracy of these devices were checked, and they were found to be similar in giving readings of the accurate concern when used interchangeably.

Fatigue level measurement

The muscular effort required to perform some activity/ job induces fatigue in the workers, which gradually increases as the workers continue to work. The level of fatigue can be measured to determine the potential success of the product intervention and its use. The use of a newly developed tool/ apparatus must be capable of inducing lesser fatigue as compared to the previous method (Singh and Karmakar, 2024).

In pouch/ sachet rework activity, blade/ cutter/ tool handling characterized by gripping/ holding and forceful hand squeezing (in an existing scenario) was predominant. Activities involving hand gripping / forced squeezing may result in fatigue effects on concerned muscles, which can be measured through Electromyography (EMG) to determine the fatigue spot accurately and with the help of a hand grip dynamometer (Alkurdi and Dweiri, 2010; Cotelez et al., 2016; Bridger 2017). Hand grip strength was thus considered a parameter for determining the probable fatigue level of workers engaged in rework activity.

Since EMG at Factory A was not possible, the use of a hand dynamometer was preferred. Various literature on fatigue measurement had previously reported that the 'Jamar' hand dynamometer was a reliable instrument (Shechtman, 2001; Mathiowetz, 2002). It was popularly adopted due to its inter-rater and test-retest reliability (Innes, 1999) and was commonly used for measuring grip strength (McDowell et al., 2012; Sanjog and Karmakar, 2019). In the current field trials, Jamar's hand dynamometer was used to measure hand grip strength. The grip strength of both left and right hands was measured for each worker at the resting state (before the start of work) and after two hours of work to estimate the fatigue level induced by performing the rework activity within two hours.

Cognitive load measurement

The measurement of cognitive load (Marras and Karwowski, 2006b; De Jong, 2010; Sanjog and Karmakar, 2015) induced while performing the job/ activity also provides insights about the ease/ adaptability and usefulness of the tool/ apparatus used and its probable success. Cognitive workload measurement and other physical load measurements can provide better insights into the merits/ demerits of the design intervention implemented. Currently, the worker's workload in industrial scenarios is being increasingly assessed using subjective measures because of practical advantages (ease of implementation and non-intrusiveness) in human-machine system evaluations (Rubio et al., 2004). The subjective workload assessment for rework activity was performed using the NASA Task Load Index (TLX) questionnaire (Hart and Staveland, 1988). It is a popular method for determining subjective workload. It helps in finding an overall workload score based on a weighted average of ratings using six subscales, namely mental demand, physical demand, temporal demand, performance, effort, and frustration level (Jung and Jung, 2001; Cao et al., 2009; Malekpour et al., 2014).

The NASA-TLX is a multidimensional scale (Appendix A.4) that provides an overall or global measure of workload and identifies specific workload components (Tiwari et al., 2009; Sugarindra, 2017). Based on a weighted average of ratings, the NASA TLX scale provides an overall workload score that helps determine the cognitive load on the worker while performing the task/ activity (Devos et al., 2020; Wang et al., 2021). Mean Weight Workload (MWW) calculated using two-tier ratings and weights for each of the six subscales of the questionnaire provides insights about the cognitive workload of the worker. The lower the MWW, the lesser the cognitive workload and the easier the job/ activity to perform. The NASA-TLX questionnaire was administered, and the MWW for the existing and improved scenarios was measured and recorded.

4.2.8.3 Biomechanical posture compatibility evaluation

A keen observation of the posture adopted while performing certain jobs/ activities and the primary body parts involved help determine the man-machine interface's compatibility (Casadio et al., 2012; Sanjog and Karmakar, 2014, 2015; Singh and Karmakar, 2024). Biomechanical posture compatibility of the tool/ apparatus with the need/ requirements of the job/ activity is a critical factor in determining its success. The tool/ apparatus developed must be biomechanically compatible, and workers must be able to use the tool/ apparatus in a neutral posture/ position, and no awkward postures shall emerge while using the tool/ apparatus (Sanjog and Karmakar, 2014, 2015; Singh and Karmakar, 2024). Such biomechanical compatibility must be assessed/ ascertained to the most critical body part involved. The most critical body part in the rework activity was the 'Wrist.' The wrist was being used to hold, move, and drag the apparatus in new condition. So, for compatibility of the highest concern, keen observation of the probable use of the wrist while performing the job/ activity was considered.

Wrist postures were physically observed while performing the rework activity using a newly developed tool/ apparatus. The wrist posture retained at various instances while holding, moving, dragging, and re-lifting to the initial condition was minutely observed to understand the biomechanical compatibility of the tool/ apparatus.

4.2.8.4 Usability evaluation

Apart from productivity and physical and cognitive adaptability, for the successful intervention in the form of a product (tool/ apparatus), there lies another critical factor, i.e., user acceptance. For the deemed success of newly developed tools/ apparatus, its usability (user-acceptance) must be high. The intended stakeholders (workers, managers, etc.) must exhibit high intent towards its use and adaptability in their routine job/ activity (Tullis and Stetson, 2004; Liang et al., 2018; Deng et al., 2019).

The System Usability Scale (SUS) (Appendix A.5) is a reliable tool/ technique for measuring product usability worldwide (Brooke, 1996; Verma and Karmakar, 2021). The researchers readily use it to evaluate the usability of their new products to adjudge their acceptance level among the intended stakeholders. It consists of a ten-item questionnaire with five response options for respondents, from 'Strongly Agree' to 'Strongly Disagree' for both positive and negative trait questions. Then, the overall score is generated and recorded utilizing its scoring and calculation matrix. The average SUS score is 68 and is generally considered 'good'; a good SUS score indicates a decent level of usability. The scores below 68 indicate a potentially serious deficiency in usability and suggest the need for substantial improvements to enhance user satisfaction. It was created by John Brooke in 1986, and it allows one to evaluate a wide variety of products and services, including hardware, software, mobile devices, websites, and applications (Bangor et al., 2008; Lewis and Sauro, 2009).

User acceptance of the devised tool/ apparatus was assessed by taking feedback from users, and the SUS was used for this usability evaluation at Factory A.

All these parameters for determining the success of the tool/ apparatus devised as a mitigating solution were measured, recorded, analyzed, and interpreted to determine its usefulness and success. A summary of all these parameters is provided in Table 4.4, which depicts the comparison between the existing and improved scenarios. The following sub-sections discuss in detail the results received and the vital insights gained from those.

Table 4.4: Factory Trials - Insights (Summary)

1. Productivity:

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
Number of pouches reworked per 15 min (average of 3 trials)	430 ± 18 pouches/ 15 minutes	1040 ± 29 pouches/ 15 minutes

2. Human Factors:

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
Physical exertion level measured utilizing Heart Rate	Resting/ before the start of the work: 80 ± 12 bpm After 2 hrs of work 86 ± 11 bpm	Resting/ before the start of the work: 81 ± 11 bpm After 2 hrs of work 84 ± 10 beats/minute
The muscular effort required and, therefore, fatigue level measured utilizing handgrip strength dynamometer (Make: Jamar & Model: J00105)	Resting/ before the start of the work Right: 40.6 ± 7.6 kg Left: 39.1 ± 8.1 kg After 2 hrs of work Right: 29.5 ± 5.6 kg Left: 30.6 ± 2.3 kg	Resting/ before the start of the work Right: 41.2 ± 5.8 kg Left: 40.3 ± 4.9 kg After 2 hrs of work Right: 35.7 ± 4.6 kg Left: 35.5 ± 3.1 kg
Cognitive workload measured using NASA-TLX questionnaire (MWW)	72.66 ± 15	45.45 ± 10

3. Wrist Posture:

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
Wrist Posture	Variable (no fixed posture)	Almost neutral

4. System Usability Scale (SUS):

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
SUS Score	(not conducted)	81 (Very Good)

The field trials depicted that the newly developed innovative safety-enriched pouch/ sachet cutter was more productive and easier to use. It was well-received by the workers and factory management.

4.3. Discussion

The current product design/ development process followed in this research, from the pre-conceptual phase to field trials, paves its way through various stages. It provides several key insights describing the peculiarity, vitality, rigor, and fundamental anchoring of the concepts theoretically and in application. These insights are discussed in detail in the coming subsections.

4.3.1 Product development phase

The critical insights gained from the product development phase, from preliminary field survey to physical prototype development, are discussed below.

Insights from the field survey

The preliminary ergo-audit conducted on the FMCG shopfloor of twenty factories located in Assam, India, provided insights about the critical context-specific work activities and tasks pertaining to FMCG that are prone to OSH risks and need immediate attention of the researchers to devise innovative mitigating solutions to improve the working conditions thereof for worker well-being. Rework of pouch/ sachet activity was considered an activity of prime concern as per the opinion gathered from the managers/ supervisors of these factories (Singh and Karmakar, 2022). As these factories were working in different levels of production scale, viz. production level, employment, work parameters, etc., it was anticipated that probably the same level of solution in the form of tool/ apparatus would not be a perfect solution for their context-specific requirements. Presumably, different level of solution in a product form will satisfy their needs. For this reason, three different levels of factories working at various scales of production levels were chosen, and those were representative of their segment, viz. MSME, large, and mega sectors. These were termed Factory A, B, and Factory C, respectively (refer to Chapter 3).

Insights from the product design phase

In this chapter, specific to the design/ development of the pouch/ sachet cutter for Factory A, the representative of the MSME sector, the product development phase initiated from understanding their specific working style and work parameters and their particular need and requirements. The current research demonstrates that the minute and careful study/ observation of work parameters of the task/ job under consideration leads to a better understanding of the exact needs and requirements of the intended user population. Effective, innovative products can be designed and developed based on identified needs and requirements by implementing design and ergonomic principles. A detailed product design and development process, ranging from conceptualization to virtual product development and its field trials, has been demonstrated in this chapter. The presently adopted methodology is in substantiation to other innovative product development techniques (Otto and Wood, 2001; Prabhu and Jain, 2015; Ulrich and Eppinger, 2016).

A proactive user participatory approach was instrumental in keeping all the stakeholders involved in the design and development process and having their suggestions, feedback, and opinions in the current research. Using a Morphological chart, many concepts were possible in the given time, and the Pugh Chart successfully revealed the best concept out of the ten concepts of 'pouch/ sachet cutter' generated earlier. Similar systematic scientific endeavors encompassing Morphological and Pugh charts have been successfully deployed by designers/ researchers in varied domains (Pugh, 1991; Mansor et al., 2014; Lin and Hsiao, 2019; Wu and Hsiao, 2019; Singh and Karmakar, 2024).

Careful consideration of anthropometric and biomechanical parameters has been incorporated while designing and developing the present 'pouch/ sachet cutter.' Various anthropometric parameters, like handbreadth with a thumb, grip inside diameter, popliteal height, etc., (Chakrabarti, 1997) were considered for designing the various product features/ dimensions while developing the virtual model of the product. These anthropometric landmarks were considered for the optimal population percentile as per the needs and requirements of the intended user population. Table 4.5 depicts some of the anthropometric considerations used in the design phase.

Table 4.5: Anthropometric considerations used in the design phase. (Source: author)

Sr. No.	Parameter/ Feature Considered	Anthropometric Landmark Considered	Population Percentile Considered	Dimension (mm)
1.	Length of tray	Half of the span akimbo (half of the elbow to elbow width)	50^{th} percentile combined data (male-female population)	425 mm
2.	Handle length	Handbreadth with thumb	95^{th} percentile (male population)	110 mm
3.	Handle diameter (cross-section)	Grip inside diameter	25^{th} percentile (male population)	46 mm
4.	Table height	Popliteal height + Thigh clearance + allowance	95^{th} percentile (male population)	(471 + 158 + 10) mm = 639 mm
5.	Seat height (if need to sit)	Popliteal height	50^{th} percentile combined data (male-female population)	419 mm

Similarly, several biomechanical considerations were carefully considered while designing the product to keep the wrist posture in the neutral position so that no Ulnar or Radial (lateral or medial) deviation of the wrist occurs while using the intended product. In addition, various ergonomic principles of hand tool design were also considered. The biomechanical features considered in this design phase are as follows:

- To keep the wrist towards a neutral range of motion and to achieve better wrist posture while using the tool, an angle of 25 degrees between the frame bar and the handle was provided on the upper part of the apparatus.
- Ergonomic principles of hand tool design were considered during this innovative pouch/ sachet cutter's concept development, handgrip strength, grip diameter, wrist posture, handbreadth, etc.
- Rubberized material for the handle was used/ given to reduce contact pressure between the palm and handle surface.

The adopted method of selecting anthropometric and biomechanical parameters for product development is in corroboration with other innovative product development studies (Sanjog and Karmakar, 2019; Verma and Karmakar, 2021; Singh and Karmakar, 2024). In the current research, the fully functional innovative product in the form of a safety-enriched pouch/ sachet cutter was developed using thoroughly explored design and ergonomics principles. It was deployed for in-depth field trials at Factory A to assess its functionality, performance, and user acceptance. The following subsection discusses the key insights gathered from the factory trials.

4.3.2 Factory trial phase

Post-development of the physical prototype of the safety-enriched cutter, the field trials at Factory A were conducted to evaluate several essential parameters deemed fit for its performance analysis and user acceptance level assessment. Table 4.4 summarizes the observations/ results of these specific parameters for the existing and improved scenarios (using a newly developed safety cutter). This comparison provides vital information and insights about the products's level of success and other relevant concerns.

The number of pouches reworked using the existing method and with improved cutter were taken into account to determine the productivity levels. Trials for 15 minutes were recorded for each worker, and three such trials were taken. The average of three trials was used for reporting purposes. It revealed that the existing method, wherein the pouch/ sachet cutting was done using a sharp cutter/ blade held in bare, slippery hands, and hand squeezing was carried out, and the workers were able to cut on average 430 ± 18 pouches. However, with the use of a newly developed safety cutter capable of cutting and squeezing in a single stroke, the average number of pouches/ sachets reworked rose to 1040 ± 29 per 15 minutes. It was a significant improvement in the context of productivity levels and efficiency. It can be attributed to the fact that while using the newly developed cutter, the workers were not forced to be more cautious (about cuts/ injuries happening while operating) while using the safety-enriched cutter wherein the blade was held in the frame of the cutter. They were able to perform swiftly as the cutter/ blade held in the frame eliminated the inherent feeling of danger that was an integral part of the earlier process, wherein the cutter/ blade was held in the bare, slippery hands and was prone to minor accidents and injuries. Moreover, productivity rose as the newly developed cutter eliminated the need for manual squeezing, thus making the task fast and eliminating the chances of contamination to a great extent.

For an assessment of the product's compatibility with the job/ activity, tool-worker interface, and related consequences, the human factor evaluation based on physical exertion level using heart rate, fatigue level measurement using handgrip strength, and cognitive load assessment using NASA-TLX was performed for the existing and improved scenarios.

Physical exertion level was measured utilizing the Heart Rate. Heart Rate was taken for each worker in the resting state, i.e., before the start of the work and after 2 hours of work. For the existing scenario, the Heart Rate before the start of work was 80 ± 12 beats/ minute (bpm) and was 86 ± 11 bpm after 2 hours of work. While using the newly operated pouch/ sachet cutter, values were 81 ± 11 bpm and 84 ± 10 bpm, respectively. From these values, it is evident that there is no major deviation in physical exertion levels while operating with the newly developed cutter. The exertion levels in both scenarios are almost in line with each other; rather, in the improved scenario, the Heart Rate values were lower at the end of the 2 hours of work. It can be concluded from the facts that the newly developed cutter is easy to operate and handle and does not exert much physical exertion on the workers, as ascertained from the Heart Rate values recorded.

The handgrip strength values measured the muscular effort required to perform the rework job/ activity and the induced fatigue. In existing scenarios, the recorded values for the resting/ before the start of the work were 40.6 ±7.6 kg and 39.1 ± 8.1 kg for the right and left hand. The obtained values for the handgrip strength after the 2 hours of work were 29.5 ± 5.6 kg for the right hand and 30.6 ± 2.3 kg for the left hand. For the improved scenario, wherein the need for manual hand squeezing was eliminated, the obtained values were 41.2 ± 5.8 kg for the right hand and 40.3 ± 4.9 kg for the left hand at the resting state (before the start of the work). At the end of 2 hours of work, the obtained values were 35.7 ± 4.6 kg and 35.5 ± 3.1 kg for right and left hand, respectively. These values show that the decrease in handgrip strength is lower in the improved scenario than in the existing scenario. It can be interpreted that using a newly developed cutter capable of auto-squeezing (by virtue of its integrated roller) helps minimize the fatigue induced by manual hand squeezing. A lot of workers' effort to manually squeeze liquid from cut pouches/ sachets is saved using the newly developed cutter. Moreover, it eliminates the chances of contamination that may occur due to liquid contents touching hands. Thus, this newly developed cutter reduces drudgery.

Cognitive Load Measurements were done by administering the NASA-TLX questionnaire and calculating the overall MWW. The obtained MWW value for the existing scenario was 72.66 ± 15, an indicator of the high cognitive workload associated with the rework activity being carried out in the existing scenario wherein the sharp cutter/ blade is held in bare, slippery hands, and manual hand squeezing was required. In such a scenario, workers must remain cautious, work slowly, and exert high manual effort (for squeezing) to perform their rework task without any standardized/ context-specific tool/ apparatus. These factors account for the higher cognitive workload, as indicated by the overall MWW values obtained. However, as a newly developed safety cutter eliminates the need to hold the cutter/ blade directly in the hand and subsequent hand-squeezing, the cognitive load decreases, as indicated by the obtained MWW value of 45.45 ± 10. Hence, it is evident that the present innovative ergonomic design intervention is capable of reducing the perceived physical and cognitive demand and effort among the workers engaged in rework activity.

Biomechanical posture compatibility evaluation for the newly developed cutter was assessed by minutely observing the 'Wrist' posture while performing the rework activity in an improved scenario. The wrist was being used to hold, move, and drag the apparatus in new condition. So, for compatibility of the highest concern, keen observation of the probable use of the wrist while performing the job/ activity was considered. It was observed that the 'Wrist' remained almost in a 'Neutral' position while performing this task. It was also observed that:

- There was no Ulnar or Radial (lateral or medial) deviation of the wrist while using the roller-based apparatus. Only a little bit of extension was present during this activity.
- While using the roller-based apparatus, the actual lateral movement happens from the shoulder joint, i.e., adduction and abduction. It happens in the range of 28 ± 6 degrees.

These observations confirmed the biomechanical posture compatibility of the newly developed cutter for this rework activity. It assures that the newly developed cutter can be used with ease, will not cause any harm while being used, and is perfectly adaptable to the needs of the rework activity. No such evaluation was possible in the existing scenario as no standard way of working exists. Workers tend to work in variable postures, particularly involving the wrist. The newly developed cutter provides a standard context-specific tool for rework activity and a standard way of working using the same. It is a major shift from a non-standardized activity towards standardization achieved via a context-specific innovative tool/ apparatus design and development approach.

User acceptance (usability evaluation) of the newly developed cutter was measured by administering the SUS questionnaire. A SUS score of 81 was obtained, depicting a 'Very Good' and 'Acceptable' usability rating, according to the adjectives shown in Table 4.6. The respondents rated for the 'positively phrased' and 'negatively phrased' questions while responding to the requirements of the SUS questionnaire. It was observed that, for odd-numbered questions (positively phrased), the responses were mostly 'agree' and 'strongly agree'; in contrast to even-numbered questions (negatively phrased), high response percentages were mostly between 'disagree' and 'strongly disagree.' As a result, an overall SUS score of 81 was obtained. It reflects the wide acceptability of the newly developed tool/ apparatus among the intended users and its success. They expressed their readiness to adapt to the newly developed innovative tool. No such evaluation was done in the existing scenario, as no new tool/ apparatus existed for assessment.

Table 4.6: SUS score and associated rating and interpretation. (Source: Brooke, 1996)

SUS Score	Adjective Rating	Acceptability
89-100	Best Imaginable	Acceptable
84-88	Excellent	
71-83	Good/ Very Good	
50-70	OK	Marginal
32-49	Poor	Unacceptable
20-31	Awful	
0-19	Worst Imaginable	

4.4 Developmental Cost

The physical prototype of the newly developed safety-enriched pouch/ sachet cutter was developed for factory trials. The representative cost for fabricating a single piece of such a prototype is depicted in Table 4.7.

Table 4.7: Representative cost for fabricating a single piece (prototype). (Source: author)

Cost Head	Tentative Cost (in USD)
Raw material	110
Fabrication charges	120
Miscellaneous charges	40
Total cost for one prototype	270

This cost is for fabricating a single prototype for factory trial. It is expected that the price of the final product (commercially available product) will be reduced to a great extent when mass manufacturing of such products is done.

4.5 Conclusion

The current chapter (Chapter 4) describes in detail the systematic user-centered product design approach followed for the design and development of a safety-enriched pouch/ sachet cutter, more particularly for the context-specific need/ requirements of 'Factory A' governed by its scale of production and work parameters. Following the current research, an innovative pouch/ sachet cutter was developed, considering ergonomic and design principles. It is capable of ensuring safety in rework activity as it eliminates the need to hold a sharp cutter/ blade in bare, slippery hands. Moreover, it reduces drudgery as it eliminates the need for manual hand squeezing and perhaps helps minimize the source of contamination. This innovative tool/ apparatus, which was designed with various anthropometric and biomechanical considerations in the development phase, was well received by factory workers and management. It fulfills their specific needs associated with their work style adopted in regard to rework activity and, in conjunction, fulfills the aim of this current research at Factory A that recites 'To design and develop a safety-enriched hand-held pouch/ sachet cutter for rework activity performed in a factory with a small-scale production level. Such a pouch/ sachet cutter must be capable enough to cut 5-10 pouches/ sachets at a time and eliminate the need to hold a sharp cutter/ blade in bare, slippery hands and hand squeezing'.

Additionally, as the product is innovative and has market potential, protecting the Intellectual Property Rights (IPR) of this tool/ apparatus was deemed necessary. Researchers have protected its IPR well in its parent country (India) and the United States (U.S.). Moreover, as this research has vast potential to be implemented at the global level, particularly in developing nations where FMCG rework is prevalent, this work was showcased on several international platforms in the form of award participation events. It was well received and commended globally, particularly by the Ergonomic and Human Factors Societies. As a matter of fact, any well-directed research conducted in a phased manner is capable of generating several scholarly outputs in the form of IPRs and reported research (journal publications). This particular research tried to derive various scholarly outputs from the conducted work as an endorsement of its probable success. As it was related to innovative product design, the IPR was a major stake, and those were secured first, and reporting to journal publication was taken later.

4.5.1 Scholarly outputs

Earnest efforts were made to derive various scholarly outputs from this research conducted at Factory A. Table 4.8 summarizes the scholarly outputs achieved from this project.

Table 4.8: Scholarly outputs from the present work. (Summary)

Component	Details	Status
Utility Patent (U.S.)	Patent No.: US 11319103	GRANTED and In Force
Utility Patent (India)	Patent No.: IN 355304	GRANTED and In Force
Design Registration (India)	Design No.: 329290-001	GRANTED and In Force
Journal Article (SCIE)	**Title:** Addressing OSH challenges in non-standardized work practices in small-scale FMCG units by introducing context-specific ergonomic apparatus	**PUBLISHED** in *WORK: A Journal of Prevention, Assessment & Rehabilitation*. https://doi.org/10.3233/WOR-240096

5

Development of Pouch/ Sachet Cutter for FMCG Factory with Medium-scale Production Levels

Abstract

The detailed design and development process of a safety-enriched pouch/ sachet cutter for the FMCG factory working at a medium-scale production level (Factory B) is presented in this chapter. Foremost, minute observations of the rework activity performed at Factory B's shopfloor were made to understand the work requirements, work posture adopted, existing work scenarios, and OSH concerns. The specific needs and requirements of the stakeholders (from the intended tool/ apparatus) were gathered through discussions. Multiple concepts of the intended tool/ apparatus were generated using a Morphological chart. Ten concepts were developed. Concept screening utilizing the various criteria finalized (based on user requirements) was done using a Pugh chart. Post-concept screening, the CAD model of the selected concept was developed to explain its operational mechanism to stakeholders. The finalized CAD model was achieved after several iterations, and a physical prototype was developed. A thorough consideration of anthropometric and biomechanical parameters was taken care of while developing the prototype. The apparatus developed was put into factory trials wherein it was evaluated for improvement of productivity and ensuring user compatibility from human factors' perspectives (physical exertion in terms of increased HR, reduction of handgrip strength, cognitive workload, etc.). Following the factory trials, the developed apparatus was found effective in mitigating safety concerns and various ergonomic stressors associated with FMCG rework at Factory B's shopfloor.

5.1 Introduction

The previous chapter, Chapter 4, discussed designing and developing an innovative pouch/ sachet cutter devised per Factory A's needs (small-scale production level). It was successfully tested and validated on the shopfloor of Factory A and was well-received by the workers and factory management of Factory A as it met their requirements (refer to Chapter 4). Afterward, Factory B (a representative of the medium-scale production level) was approached with the innovative product developed and its trial data results. Upon discussion with various stakeholders, it was found that this tool/ apparatus will not be able to cater to their needs as their work demands and parameters differ from the capabilities/ limits of the presently designed and developed safety cutter for Factory A. As such, it was decided to gather the context-specific requirements of Factory B further concerning their anticipated pouch/ sachet cutter that would probably meet their requirements. The following sections and sub-sections elucidate the design and development process and related insights in the purview of the innovative pouch/ sachet cutter developed for Factory B.

5.1.1 'Factory B': FMCG factory with medium-scale production level

A factory unit located in Guwahati city engaged in manufacturing personal care products (hair oil, serum, cosmetics, etc.) working under a semi-automated production setup was selected for further rigorous research and for proposing an innovative design intervention for the rework activity of that factory. This production unit falls under medium-scale production levels (large sector) as it engages automation for several of its production facilities and is capital-intensive. Still, many of its production processes remain labor intensive and utilize many permanent and contractual employees. However, the reworking of pouches/ sachets was done manually in this factory, too. Since the researcher had an NDA with the factory management, this factory unit, for anonymity's sake, is termed 'Factory B' in the subsequent sub-sections. Factory B is the representative of the FMCG factories operating under medium-scale production levels owing to the large number of workers engaged and the subsequent increase in production capacity.

The selected Factory B was manufacturing hair oil, filling the manufactured hair oil in both bottles and pouches/ sachets. The majority of its manufactured hair oil was filled in pouches/ sachets. Factory B had a workforce of more than 400 employees but less than 1000 workers. Few were regular employees, and others were contractual/ casual laborers. The researcher followed the same strategy (refer to Chapter 4) of having regular visits to the factory shopfloor, understanding the demographic details of workers engaged, work elements of the job under consideration, workstation features and details (existing scenario), productivity and efficiency (existing scenario), posture evaluation, associated safety concerns, and their occurrence, etc. to gain insights about the rework activity carried out at Factory B shopfloor.

5.1.2 Insights from the survey/ field observations

A minute and careful field observation of the rework activity being carried out on Factory B's shopfloor revealed several insights related to production setup, work demand, risk factors, essential functions/ subfunctions to be performed, context-specific needs/ requirements from the intended innovative design intervention, etc. These are summarized below:

5.1.2.1 Production level, work process, and urge for innovative solution

Although working under a large-scale production setup, Factory B usually engages contractual labor for rework. Typically, eight/ ten workers are exclusively involved in this non-standardized work activity daily and remain engaged in recovering the in-filled liquid content out of the defective pouch/ sachet that needs to be re-filled afresh in the new pouch/ sachets. They remain busy in their work for the shift of twelve hours, out of which their work extends for nine to ten hours. They work while sitting and cut the defective pouch/ sachets by taking the long strips of the pouch/ sachet in their hand and folding them to cut several pouches/ sachets at an instance (usually five or six pouches/ sachets). Cutting of the pouch/ sachet is done with the help of a sharp cutter/ blade that is often held with bare, slippery hands. Once the adequate number of pouches/ sachets are cut, the workers then squeeze those with their hands (forceful manual extraction) to extract the in-filled liquid within the temporary containers/ bins. This hand-squeezing spoils their hands with liquid content, and their hands often remain drenched with the hair oil. Once it is done, they then take the next strips to repeat the cutting and squeezing task, which continues for the whole day. On average, they need to rework almost 0.2 million defective pouches/ sachets daily with varying hourly productivity levels. Their efficiency varies per hour, depending upon the cutter/ blade condition. They tend to cut more pouches/ sachets when the blade is sharp. Once the blade gets blunt, the number of cut pouches/ sachets drops. Since their hand gets spoiled with liquid content and become slippery, it is difficult to hold the cutter/ blade; they tend to work slowly and with caution and intermittently wipe out their hand with the rough clothes kept side for wiping purposes. It was noted that Factory B has a higher production rate of pouch/ sachet production and similarly has a higher number of rejected pouch/ sachets (almost double as compared to Factory A) for various reasons and thus poses a need for reworking a higher number of pouch/ sachets as compared to Factory A.

As already discussed in Chapter 4, the factory shopfloor workers and factory management were concerned with the difficulties and risks associated with the rework activity and considered it a task of critical concern and sought help from the researchers to address the existing adverse situation and propose innovative design interventions in the form of context-specific tools/ apparatus that may improve the situation at their factory shopfloor premises. For this purpose, a similar design and development strategy (as followed for the pouch/ sachet cutter development for Factory A) was followed (refer to Chapter 4). However, the context-specific details of Factory B were considered while designing and developing the innovative product.

5.1.2.2 Need/ requirements from the intended solution

By means of discussions/ interviews, the specific characteristics (desired needs) of the intended innovative safety-enriched tool/ apparatus for Factory B were assessed. These are listed below:

- It may be manually operated or semi-automatic
- It may be capable of cutting 25-100 pouches at a time (cutting a medium number of pouches, multiple pouch/ sachet strips at a time)
- It may have medium-level complexity of mechanism (in-house repairs possible)
- It should be of compact shape and size (occupy lesser space)
- It should have an integrated container for the collection of extracted liquid

5.2 Development of Pouch/ Sachet Cutter for FMCG Factory with Medium-scale Production Levels

This section describes the design and development process followed to develop a context-specific safety-enriched tool/ apparatus for safely reworking the pouches/ sachets on the Factory B shopfloor.

5.2.1 Aim

To design and develop a safety-enriched pouch/ sachet cutter for rework activity performed in a factory with a medium-scale production level. Such a pouch/ sachet cutter must be capable of cutting 25-100 pouches/ sachets at a time and eliminate the need to hold a sharp cutter/ blade in bare, slippery hands and hand squeezing.

5.2.2 Product design and development process

To carry on the current research and proceed toward fulfilling the aim of the current chapter, a design and development process engaging various ergonomic and design principles was followed and is presented in detail in the following subsections. The generic product development process (refer to Chapter 4, Section 4.2.2.1) was deployed to devise an innovative tool/ apparatus for Factory B.

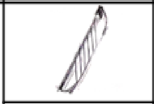
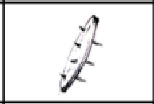
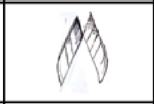
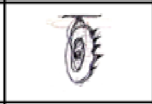
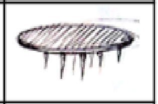
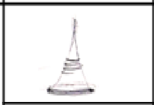
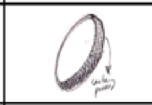
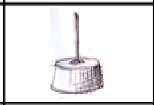
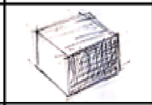
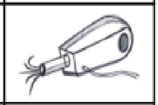
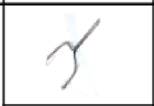
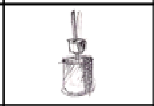
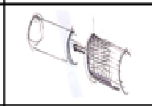
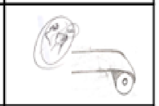
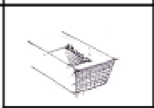
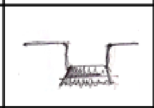
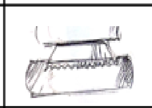
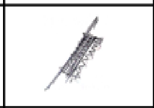
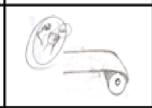
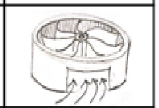
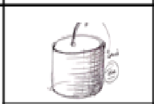
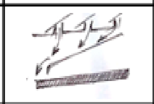
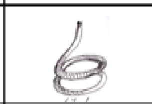
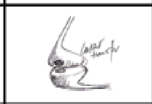
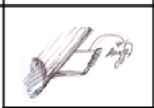
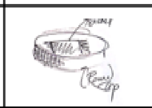
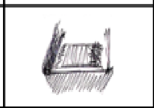
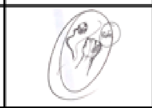
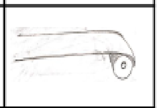
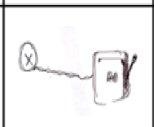
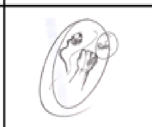
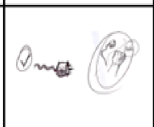
5.2.3 Product development process adopted in current research

The current research (at Factory B shopfloor) adopted a similar product design approach (refer to Chapter 4, Section 4.2.3) based on well-thought design and ergonomics principles. It was broadly conducted in three phases, viz. 1) Field Survey Phase, 2) Concept Development & Prototyping Phase, and 3) Field Trials. It employed several Human Factors (HF)/ ergonomic principles. The initial field survey (refer to Chapter 4, Section 4.2.3.1) was conducted, and context-specific work parameters for factory B were understood to design and develop innovative products for their needs/ requirements. For finalizing various sub-functions of the intended product/ tool, the insights from the factory visits and user (workers, safety managers, management) requirements were given due consideration.

5.2.4 Concept generation

A Morphological chart was used for multiple concept generation to move further with the design and development process of a safety-enriched pouch/ sachet cutter for Factory B's specific needs (refer to Chapter 4, section 4.2.4). Table 5.1 illustrates the Morphological chart used to generate the alternate concepts of the intended product.

Table 5.1: Morphological chart generated for pouch/ sachet concept generation. (Source: author)

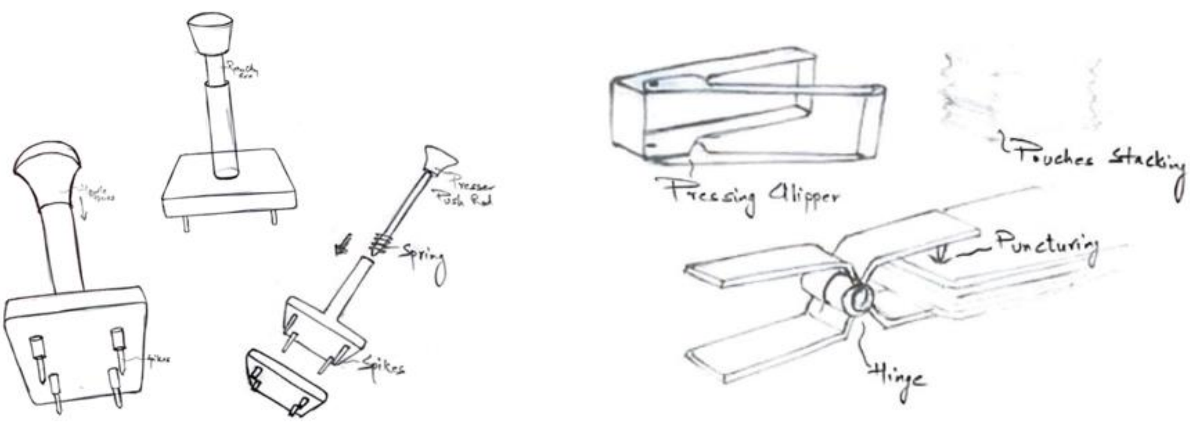
Sub Function \ Solution		Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Cutting pouch to extract liquid	**1**	 Surface Cutting	 Pricking	 Puncture	 Scissor	 Rotating Blade	 Spikes
Extracting complete liquid out of cut pouch	**2**	 Funnel Sucking	 Roller Pressing	 Wheel Pressing	 Tapping	 Block Pressing	 Suction
Moving/ holding / supporting the apparatus	**3**	 Body Frame	 Vertical Frame	 Between Rollers	 Flap Press	 Stick/ Plunger	 Manual Drag/ Belt
Placing the uncut pouches	**4**	 Guide Rail Bin	 Teeth Friction	 Drum Top	 Direct Rubbing	 Hand Held/ Belt	 Cavity
Collecting the extracted liquid	**5**	 Solid Drum Pipe	 Nozzle Dripping	 Direct Pipe	 Bucket/ Tub/ Bin	 Contact Transfer	 Funnel
Feeding the incoming pouches	**6**	 Roller Sucking	 Spike Hitting	 Rolling Gun	 Guide Rail Feed	 Manual Push	 Belt/ Flat Surface
Providing energy for apparatus action	**7**	 3 Phase Power	 DC Power	 Manual Effort	 Electro-mechanical		

Based on inputs from the Morphological chart (Norris, 1963; Verma and Karmakar, 2021; Singh and Karmakar, 2024), the ten concepts were generated (refer to Chapter 4, Section 4.2.4) using an amalgamation matrix. Table 5.2 below depicts the amalgamation matrix of the concepts generated per the specific needs/ requirements of the anticipated innovative pouch/ sachet cutter for factory B.

Table 5.2: Amalgamation matrix for pouch/ sachet concept generation. (Source: author)

Concept	An amalgamation of a matrix for conceptual sketch
Concept Sketch 1	(1,6) + (2,4) + (3,5) + (4,4) + (5,4) + (6,2) + (7,3)
Concept Sketch 2	(1,3) + (2,4) + (3,1) + (4,4) + (5,4) + (6,4) + (7,3)
Concept Sketch 3	(1,1) + (2,2) + (3,1) + (4,1) + (5,2) + (6,4) + (7,3)
Concept Sketch 4	(1,5) + (2,2) + (3,6) + (4,5) + (5,5) + (6,6) + (7,2)
Concept Sketch 5	(1,1) + (2,5) + (3,6) + (4,5) + (5,5) + (6,6) + (7,1)
Concept Sketch 6	(1,5) + (2,2) + (3,2) + (4,5) + (5,1) + (6,6) + (7,3)
Concept Sketch 7	(1,3) + (2,5) + (3,6) + (4,5) + (5,4) + (6,6) + (7,3)
Concept Sketch 8	(1,6) + (2,5) + (3,1) + (4,3) + (5,4) + (6,2) + (7,4)
Concept Sketch 9	(1,1) + (2,2) + (3,2) + (4,1) + (5,1) + (6,4) + (7,3)
Concept Sketch 10	(1,3) + (2,5) + (3,6) + (4,5) + (5,4) + (6,2) + (7,4)

The following ten concepts were generated as per the amalgamation matrix. A brief description of each concept is given below:

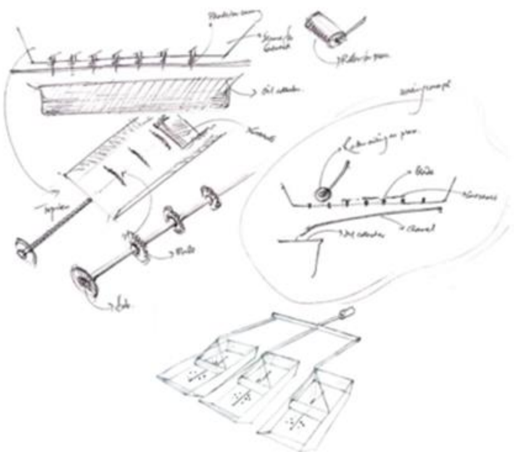


Concept 1 **Concept 2**

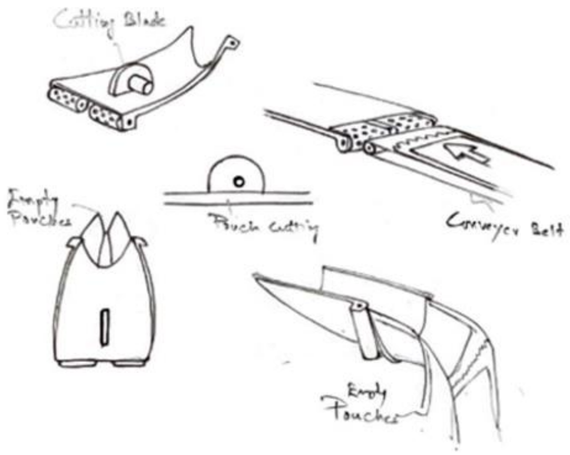
Figure 5.1: Different pouch/ sachet cutter concepts developed (concepts 1 and 2). (Source: author)

- **Concept 1:** This is a spike-hitting and tap-pressing-based concept. It has a long plunger push rod containing a spring mechanism to move up and down the spike-based flat bed provided at its bottom. It consists fixed spike receiving cum guideway, upon which the stack of pouches/ sachets can be kept, and the plunger-push rod can be directly tapped to puncture the pouches, and by subsequent pressing, the extraction of the liquid happens. It can be mounted on any bucket/ container to collect the extracted oil easily.

- **Concept 2:** In this concept, the stack of pouches/ sachets is punctured utilizing the sharp-edged puncturing nail provided on the upper flap of the clipper-based device that has hinge-based collapsable flaps to move up and lower down both flaps as per need. Once the puncturing of the stack of pouches/ sachet is done, the closing in flaps squeezes the liquid content out of the pouches/ sachets, which can further be collected in any additional bucket/ container.



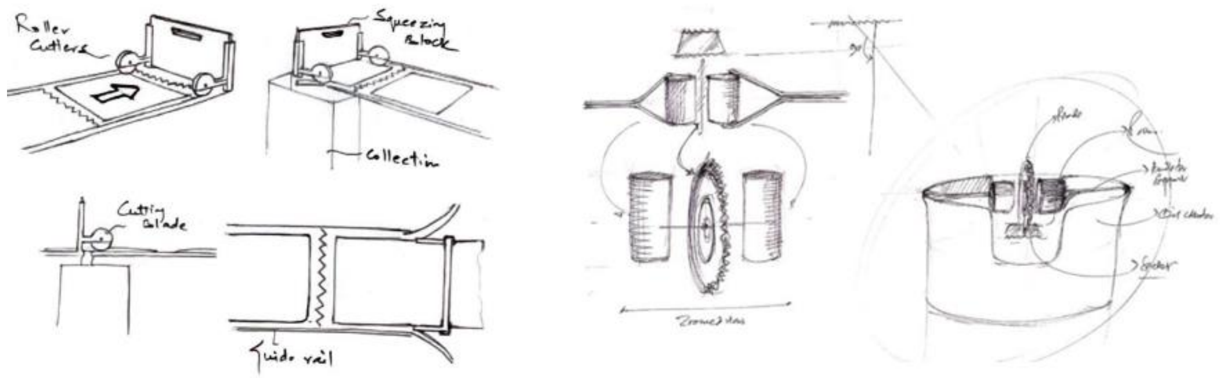
Concept 3



Concept 4

Figure 5.2: Different pouch/ sachet cutter concepts developed (concepts 3 and 4). (Source: author)

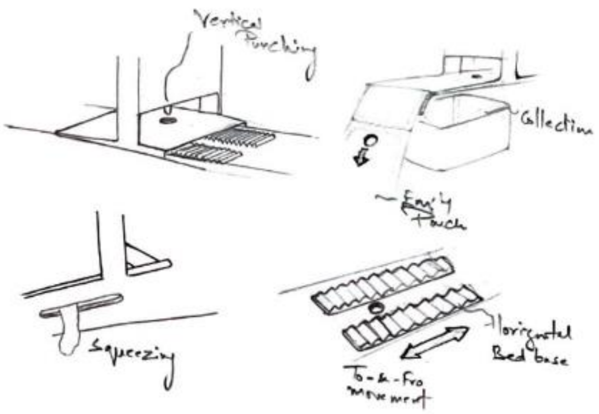
- **Concept 3:** This is an integrated glider cum collection bin concept that utilizes the blade holding frame loaded with a roller at its far end. It consists of many such (multiple) glider assemblies and roller frames attached to a single holding unit that helps drag the roller frame assembly within glider cum collection bins to cut and subsequently squeeze the pouch/ sachet strips to extract liquid content out of those. Multiple cutter and roller frames attached to single moving/ dragging unit enables this apparatus to cut/ squeeze multiple pouch/ sachet strips in multiple glider cum collection bins.
- **Concept 4:** This is a conveyor-based concept wherein the pouch/ sachet strip moves upon the belt, and the pouch/ sachets are cut through the rotating blade mounted within a pre-designated location within the conveyor belt. The cut pouch/ sachets further move through the rollers provided towards the narrowing end of the conveyor. The narrow end helps steepen the fall of extracted liquid in the collection unit, and the empty pouches fall into the dedicated trash collector provided on the narrow end. The conveyor belt may be energized using a Direct Current (DC) power unit.



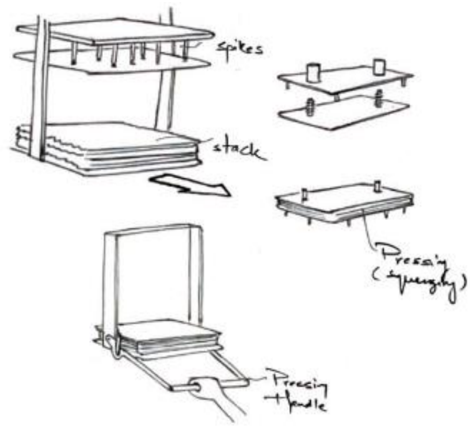
Concept 5 | Concept 6

Figure 5.3: Different pouch/ sachet cutter concepts developed (concepts 5 and 6). (Source: author)

- **Concept 5:** This is another conveyor-based concept wherein the blade surface cutting is utilized to cut open the incoming pouch/ sachet strip at two points towards the horizontal (lengthwise) ends. Two roller cutter blades are attached at the end of the conveyor that cut the pouch/ sachet strip from the sides, and as the pouch/ sachet gets cut from the sides, the resisting block (squeezing block) mounted at an optimal height presses them to extract the liquid out of those and the empty pouch/ sachet passes through it. Integrated collection bins are mounted on both sides of the conveyor belt to collect the draining liquid as the pouch/ sachet is cut open through both sides.
- **Concept 6:** In this concept, within an integrated collection bin, in the middle lies a cutting and squeezing assembly mounted diametrically through the upper end of the container. Two openings (recesses) are provided on the container body to act as opening ends (for incoming pouches/ sachets) and exit for empty pouches/ sachets. The incoming pouches are fed through the conveyor belt, and the empty pouch moves out through the same, which passes through the recesses. The pouch/ sachet cut through the rotating blade gets squeezed through the rollers, and the extracted liquid is collected in the integrated bin.



Concept 7

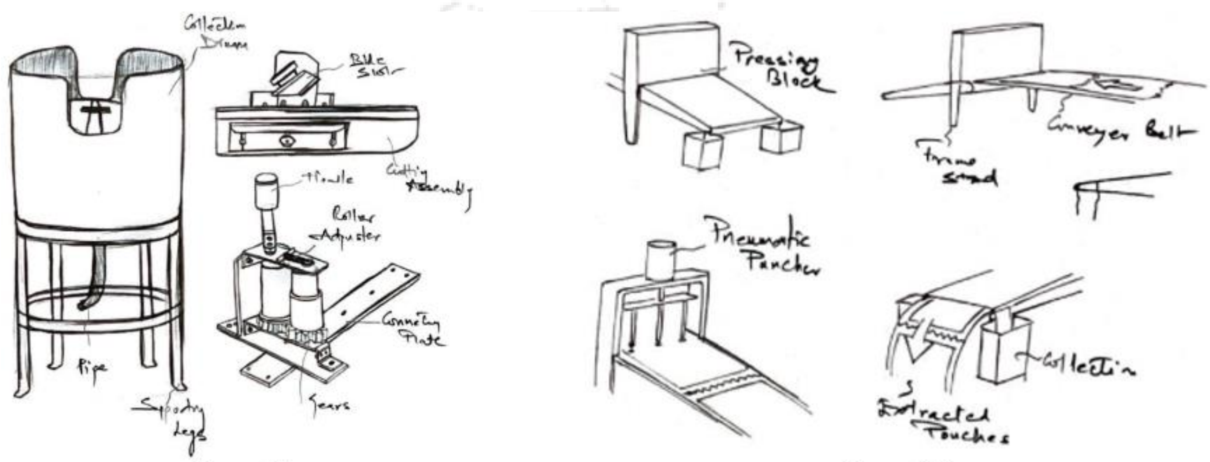


Concept 8

Figure 5.4: Different pouch/ sachet cutter concepts developed (concepts 7 and 8). (Source: author)

- **Concept 7:** This is a static punching-based concept wherein the incoming pouch/ sachet strip loaded on a to-and-fro moving belt gets punctured in the middle while passing through the puncturing frame assembly. As the pouch/ sachets get punctured, a tapping block is dragged against those to extract the liquid content that further gets collected in the separately provided bucket/ collection bin. The empty pouches/ sachets fall on the other end of the belt and are collected in trash containers provided separately.
- **Concept 8:** In this concept, the heavy spike-based rectangular board base is utilized for piercing and subsequently squeezing the pierced pouch/ sachet stacks placed on the guideway provided at the bottom of the frame-based apparatus. A handle-operated frame board is provided to move up/ lower down the spike-board to press upon the pouch/ sachet stack and retract once the piercing and squeezing are done. It can be operated with the hand pull or may be attached to an electric drive to achieve a similar function. The extracted liquid can be collected within a separate bucket/ container provided beneath the pressing component.
- **Concept 9:** This concept consists of three dedicated assemblies for cutting, squeezing, and containing extracted liquid in an integrated form. The cutting assembly has a guideway for multiple pouch/ sachet strip insertion in a vertical position and uses a side-ways placed cutter for cutting the incoming pouch/ sachets. While linearly moving through the cutter assembly, the cut pouches pass through the rotating rollers to get squeezed and let the in-filled liquid drain out. The drained liquid is further collected within the integrated container that can be connected to the main reservoir. Rotation of the rollers is achieved via the handle provided at the top and gears at the bottom.

- **Concept 10:** In this concept, the incoming pouch/ sachet strip is punctured at multiple slots utilizing the pneumatic-based puncturing block capable of moving up and down on the conveyor at designated slots. Once the puncturing block comes down and punctures the pouch/ sachet strip, the pouch/ sachet strip moves forward, wherein the optimally placed pressing block squeezes the pouch/ sachet to extract the liquid out and let the empty pouch/ sachet pass through, which further gets collected in trash bin provided separately. The extracted liquid content gets collected in a separate collection bin placed at the desired place to work efficiently.



Concept 9 Concept 10

Figure 5.5: Different pouch/ sachet cutter concepts developed (concept 9 and 10). (Source: author)

5.2.5 Concept screening

Post-concept generation, the concept screening was done utilizing the Pugh Chart (refer to Chapter 4, Section 4.2.5). Various selection/ screening criteria were finalized based on user requirements and priorities mentioned by the stakeholders (workers, safety in charge, management). In the present context, the concept '6' was chosen as the 'DATUM' or reference. Based on concept screening, concept number 9 (Figure 5.6) was selected for further development. Table 5.3 illustrates the Pugh Chart (Pugh, 1991) deployed for concept screening in the context of Factory B.

Table 5.3: Pugh chart for pouch/ sachet concept screening. (Source: author)

Selection Criteria	Weight	Concept Number									
		1	2	3	4	5	6	7	8	9	10
Safety in interacting with cutting mechanism	5	-	-	-	-	-		+	-	+	+
Efficient extraction of in-filled liquid from pouches	5	-	-	+	-	+		-	-	+	+
Ease of placing and feeding uncut pouches	4	+	+	-	+	+	D	-	+	S	+
Ease of extraction of in-filled liquid content	4	-	-	+	-	-	A	-	-	+	-
Ease of collection of in-filled liquid content	3	-	-	+	-	+		+	-	S	+
Ease of collecting/ removal of extracted pouches	3	-	-	-	+	+	T	+	-	+	-
Provision for in-house maintenance	3	-	-	+	-	-	U	-	-	S	-
Compactness	2	+	+	-	-	-		-	-	S	-
Low complexity (lesser number of mechanisms)	1	+	-	-	-	-	M	-	-	-	-
Cost	1	-	+	-	-	-		-	-	-	-
Weighted SUM of +		+7	+7	+15	+7	+15	0	+11	+4	+17	+17
Weighted SUM of –		-24	-24	-16	-24	-16	0	-20	-27	-2	-14
Net Value		-17	-17	-1	-17	+1	0	-9	-23	+15	+3

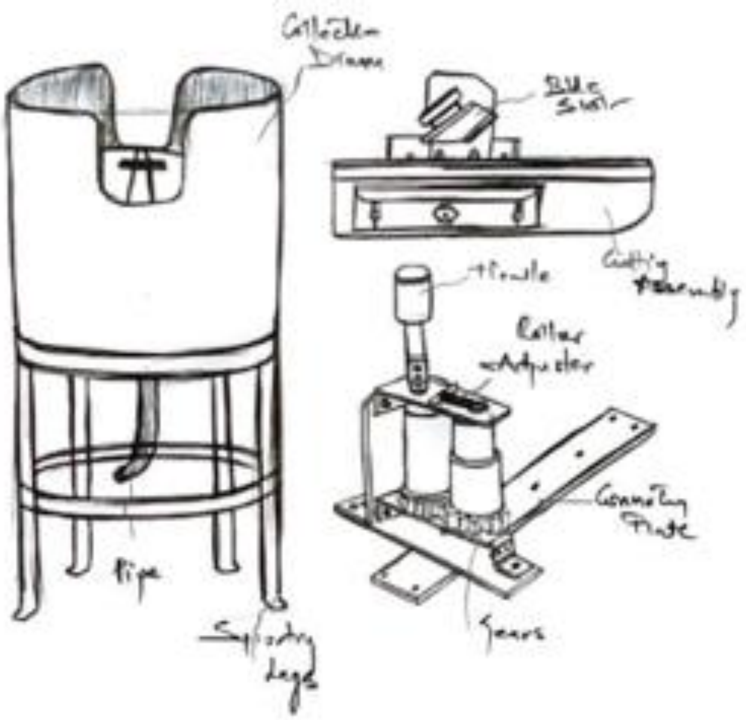


Figure 5.6: Concept selected (initial sketches). (Source: author)

5.2.6 Virtual mock-up development

Further, the CAD model for concept '9', the best concept conceived for the intended purpose of safely cutting and squeezing pouches/ sachets, was taken up as the next step in the present product design and development process. The initial CAD model was shown to the stakeholders on a laptop screen, and the operational mechanism was explained to get their feedback. Following their inputs, the final iterated CAD model of the intended pouch/ sachet cutter was prepared, as shown in Figure 5.7.

Figure 5.7: Pouch/ sachet cutter (CAD model renderings). (Source: author)

Figure 5.7 illustrates the various views of the product developed in a rendered form. The side view and the perspective view of the product developed in CAD are depicted in this figure, respectively. The digital model helped assess the aesthetic features of the intended product (form, look, finish, etc.). Various human factor principles were considered while developing the final model of the product. The anthropometric and biomechanical considerations focused on hand anthropometry, wrist's range of motion, overall posture required for using the tool/ apparatus developed, dimension of developed tools according to intended posture, and corresponding workstation, etc., were primarily considered while designing the apparatus. For the development of the tool/ apparatus, the Indian Anthropometric Database (Chakrabarti, 1997) was considered. Several parameters were considered for determining product features using different population sizes/ samples from that database.

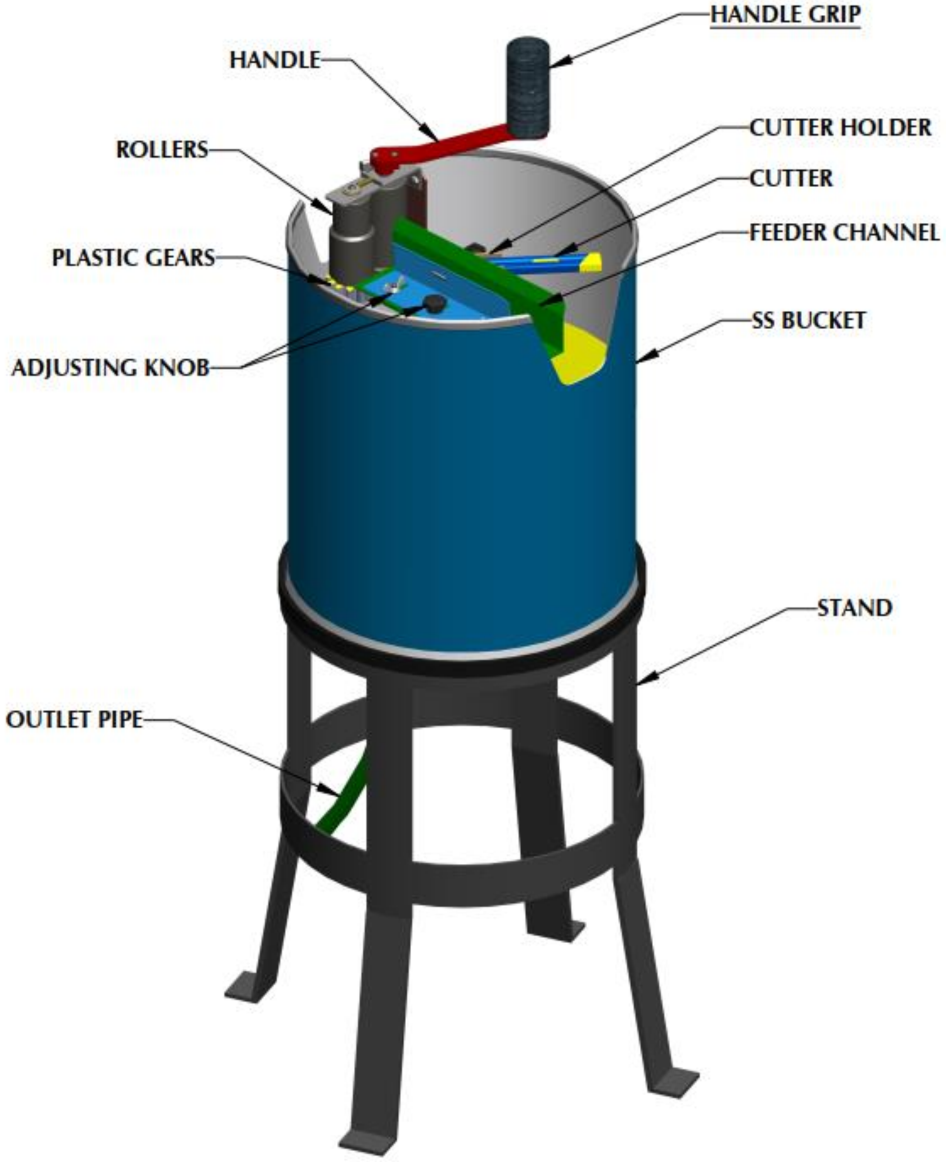


Figure 5.8: Pouch/ sachet cutter (basic part details). (Source: author)

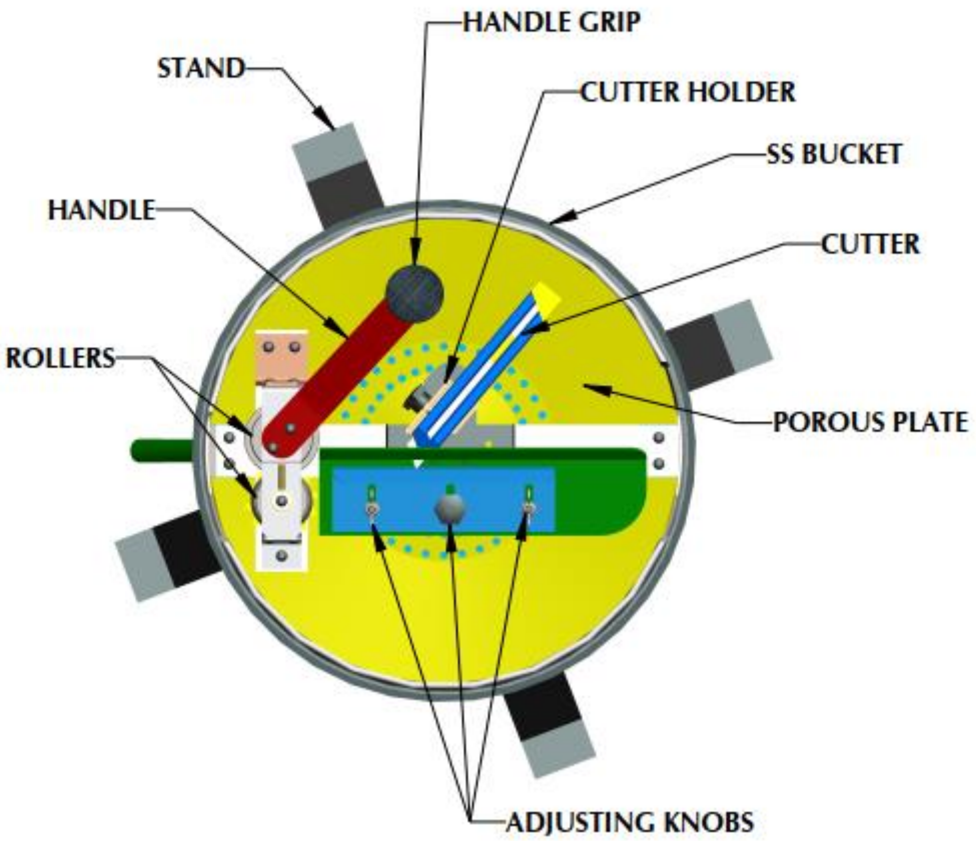


Figure 5.9: Pouch/ sachet cutter (basic part details). (Source: author)

Figures 5.8 and 5.9 illustrate a few of the basic part details of the intended product. Various parts of the pouch/ sachet cutter are presented in these figures to gain a preliminary understanding of the working/ operation of this pouch/ sachet cutter to be developed for Factory B.

Figures 5.10 and 5.11 show the various views of the product developed in a wireframe form. Figure 5.12 depicts the main assemblies/ mechanisms of the pouch/ sachet cutter. The complete product (pouch/ sachet cutter) comprising several integral mechanisms is illustrated in Figure 5.12. The overall product is labeled with part number (100), and its other mechanisms are listed as part numbers (200), (300), and (400). This part name labeling helps better understand the working and functioning of the apparatus/ tool under development and is discussed in detail in subsequent sub-sections.

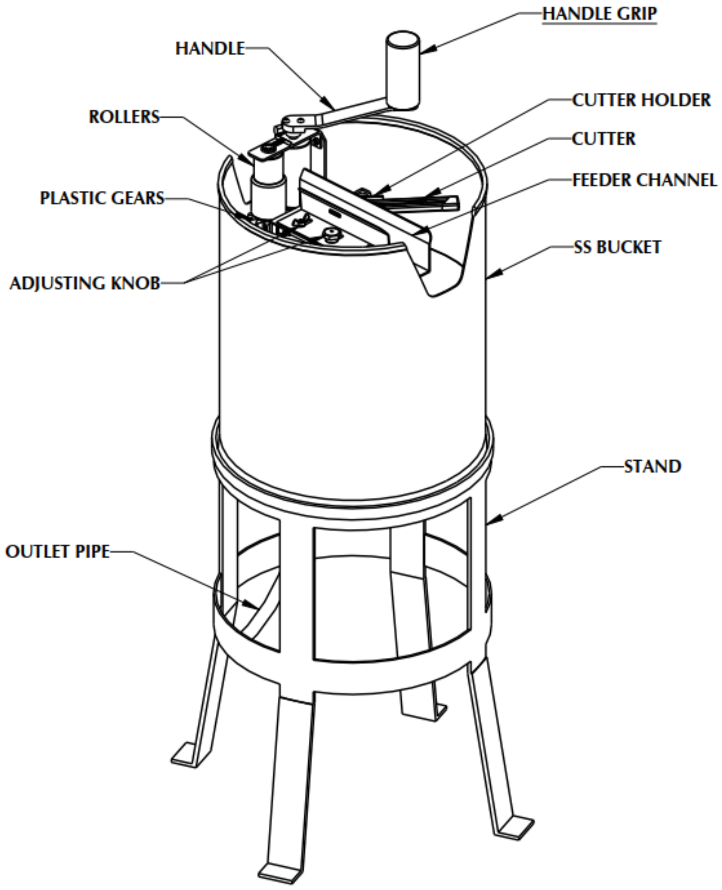


Figure 5.10: Pouch/ sachet cutter (CAD model wireframe). (Source: author)

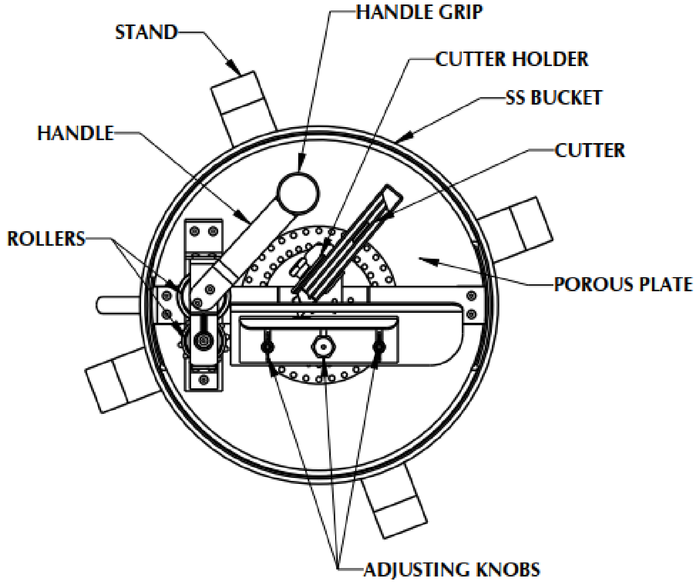


Figure 5.11: Pouch/ sachet cutter (CAD model wireframe). (Source: author)

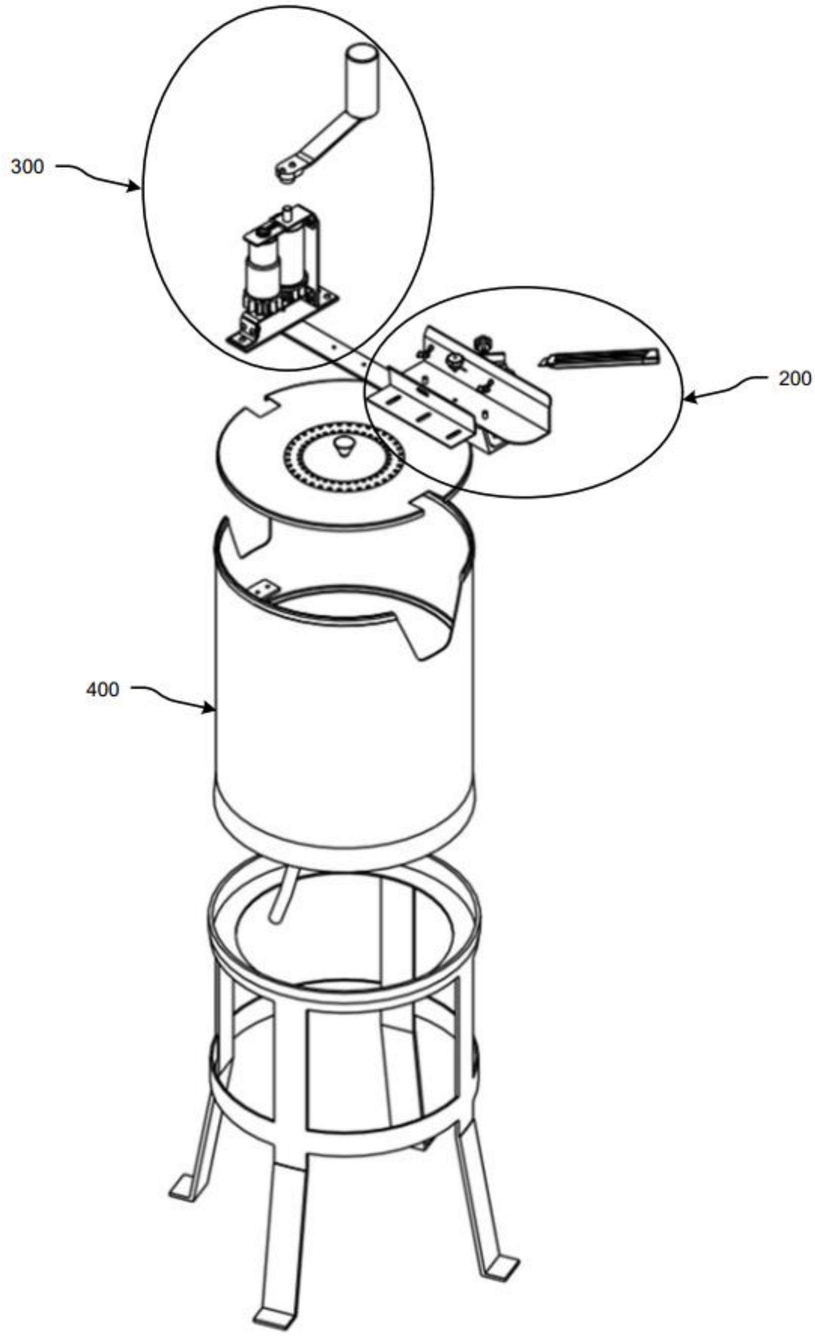


Figure 5.12: Pouch/ sachet cutter (complete product with sub-assemblies). (Source: author)

Figures 5.12 and 5.13 illustrate the essential part details of the pouch/ sachet cutter with part numbers. The newly developed safety cutter (100) comprises three major assemblies/ mechanisms: cutting and sliding assembly (200), roller assembly (300), and container assembly (400). A detailed construction/ working/ operation of this pouch/ sachet cutter (apparatus) is explained with the help of these main parts and other subpart numbers, as indicated in the following paragraphs. Figure 5.13 illustrates the different views of the intended apparatus for rework activity.

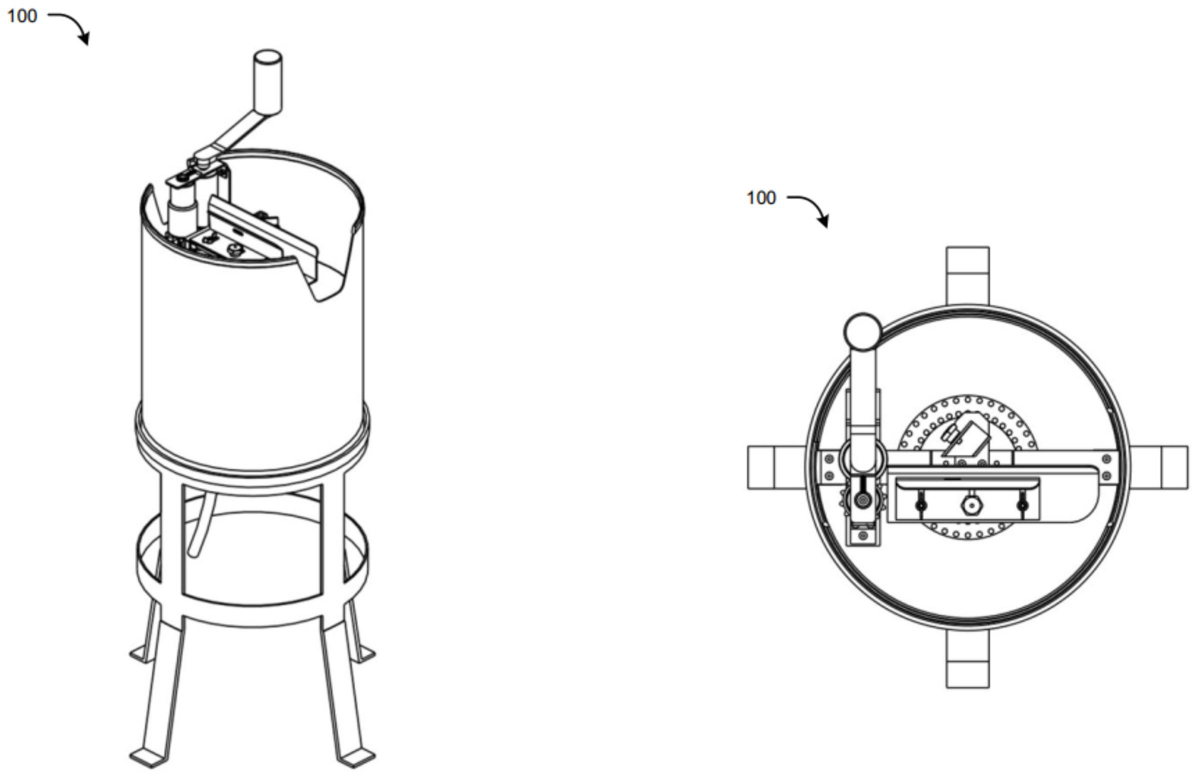


Figure 5.13: Pouch/ sachet cutter (various views). (Source: author)

The present pouch/ sachet cutter (100) includes a cutting and sliding assembly (200), a roller assembly (300), and a container assembly (400). The cutting and sliding assembly (200) is configured to enable linear movement of sachets fed therethrough and simultaneously cut them, using a cutting blade mounted thereon, as they move along a linear direction of the cutting and sliding assembly (200). The roller assembly (300) is configured adjacent to the cutting and sliding assembly (200) along a longitudinal direction of the cutting and sliding assembly (i.e., the direction of linear movement of the pouches as they are fed through the apparatus) such that rollers of the roller assembly can pull the sachets/ pouches through the cutting and sliding assembly (200). As shown therein, the roller assembly (300) includes a pair of rollers such that the pouches are gripped between the rollers and squeezed as they are pulled. The container assembly (400) includes a container that receives/ holds the extracted contents of the sachets/ pouches (recovered/ extracted oil). The cutting and sliding assembly (200) and the roller assembly (300) are mounted within the container such that squeezed-out contents of one or more sachets/ pouches are collected directly within the container. Further, the mounting of the cutting and sliding assembly (200) and the roller assembly (300) within the container is configured to enable feeding of the pouches from a recess, such as recess, on one end of a diametrical side of the container, and the processed pouches with their contents squeezed-out comes out from other recess lying on another end of the diametrical side of the container. The workings of all three major assemblies are discussed in detail in the following paragraphs.

Cutting and slide assembly

Figures 5.14- 5.16 illustrate the different views of a cutting and slide assembly of the pouch/ sachet cutter, along with its various subparts.

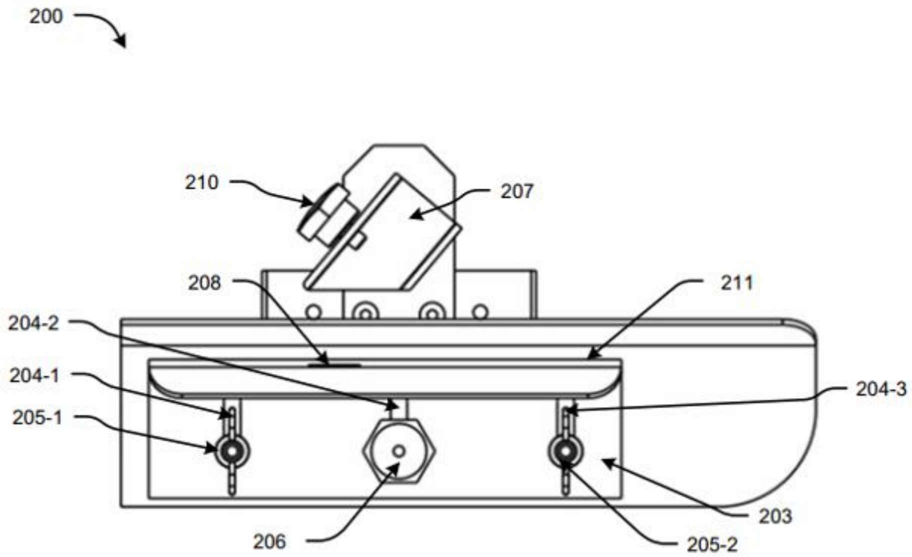


Figure 5.14: Cutting and slide assembly (part details). (Source: author)

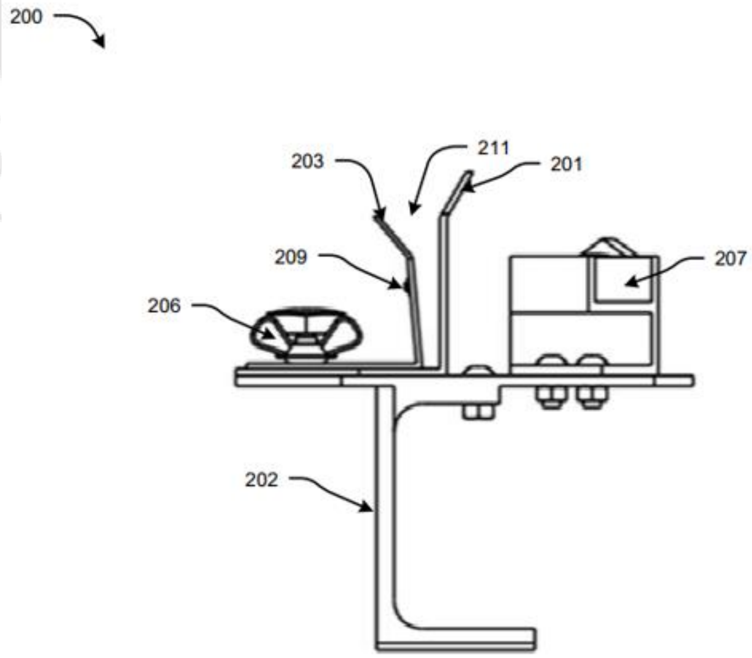


Figure 5.15: Cutting and slide assembly (part details). (Source: author)

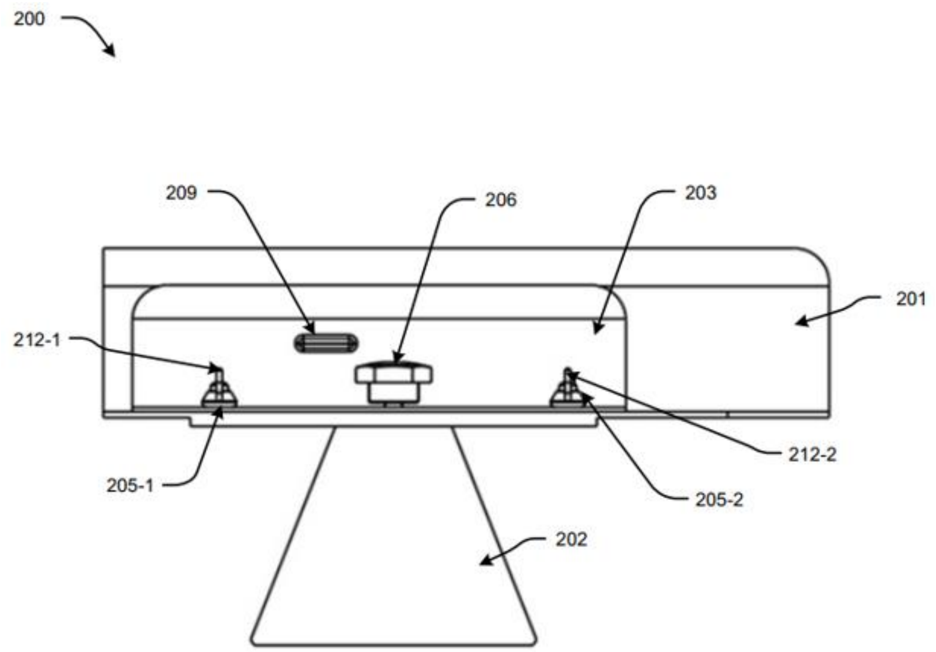


Figure 5.16: Cutting and slide assembly (part details). (Source: author)

The cutting and slide assembly (200) includes an L-shaped base plate (201) mounted upon a holding frame (202). Further, an L-shaped adjusting plate (203) is mounted on the L-shaped base plate (201) such that there is a gap between the vertical members thereof. The gap between the vertical members of the L-shaped base plate (201) and the L-shaped adjusting plate (203) forms a feeder channel (211) for accommodating the pouches and allowing their linear movement along a longitudinal direction of the L-shaped base plate (201) and the L-shaped adjusting plate (203). As can be understood, the gap defines the width of the feeder channel (211) and controls the thickness of the pouch or stack of pouches that can be fed through the feeder channel (211).

The L-shaped adjusting plate (203) is movably mounted on the L-shaped base plate (201) such that the gap, i.e., the width of the feeder channel (211), can be adjusted by lateral movement of the L-shaped adjusting plate (203). To enable adjustment of the width of the feeder channel (211), an adjustment mechanism is provided that can include two or more slots, such as slots (204-1, 204-2, and 204-3), as shown in 5.14 (hereinafter collectively referred to as slots 204) provided on the L-shaped adjusting plate (203) and two or more studs mounted on the L-shaped base plate (201). The L-shaped adjusting plate (203) can be coupled to the L-shaped base plate (201) by engaging the slots (204) with the corresponding studs, such as studs 212-1 and 212-2, shown in Figure 5.16 (hereinafter collectively referred to as studs 212), and thereafter fixed by tightening wing nuts (205) and a star-type plastic head-handle nut (206) over the studs

(212). In an application, there can be three slots (204) with two wing nuts (205) provided on the outer studs (212) and one star-type plastic head-handle nut (206) provided on the middle stud (212).

To facilitate the cutting of the pouches fed through the cutting and sliding assembly (200), a blade holder (207) is provided mounted on the holding frame (202). The blade holder (207) can be configured to hold any of the cutting blades available off the shelf. The cutting blade can be adjustably and removably held on the blade holder (207) in a horizontal orientation. The blade holder (207) includes an adjusting knob (210) to tighten and firmly hold the cutting blade in a desired position, such as at a required length projecting within the feeder channel (211) through a cut slot (208) provided on the L-shaped base plate (201). The projecting cutting blade enables the cutting of the pouches inserted through the feeder channel (211). The L-shaped adjusting plate (203) is provided with a dimple, such as a dimple (209), to create a pocket/ recess on the inner side of the L-shaped adjusting plate (203). The dimple (209) is located such that a sharp tip of the cutting end of the cutting blade, when the cutting blade is fitted in the manner described above, is accommodated within the pocket/ recess created by the dimple (209). This can prevent accidental injury to a user from the sharp tip of the cutting blade as the user feeds the pouches through the feeder channel (211).

From the above-discussed constructional details, it is evident that the multiple pouch/ sachet strips can be fed into the innovative pouch/ sachet cutter through its cutting and slide assembly, and a cutter/ blade can cut the forward moving pouch/ sachet strips before entering into the roller assembly (300).

Roller assembly

Figures 5.17 - 5.20 illustrate the different views of the roller assembly of the pouch/ sachet cutter, along with its various subparts.

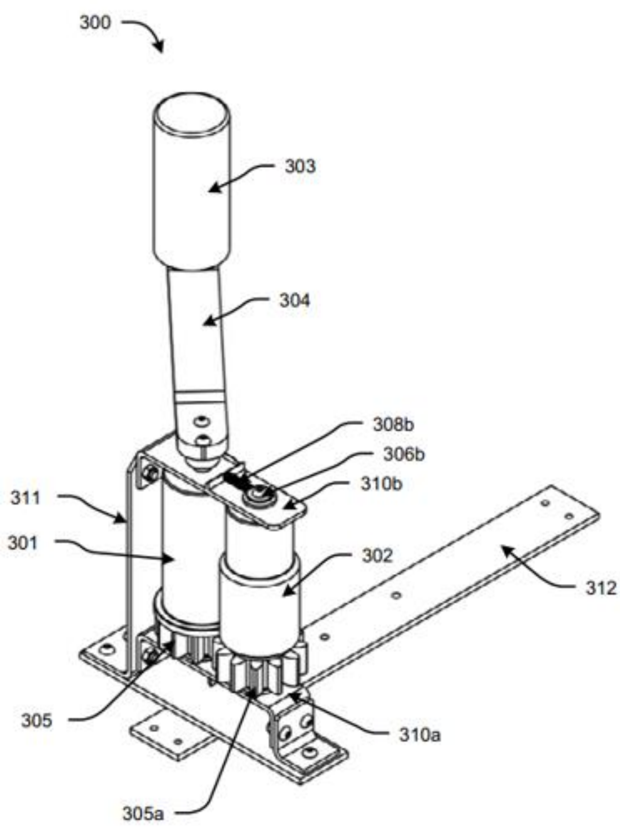


Figure 5.17: Roller assembly (part details). (Source: author)

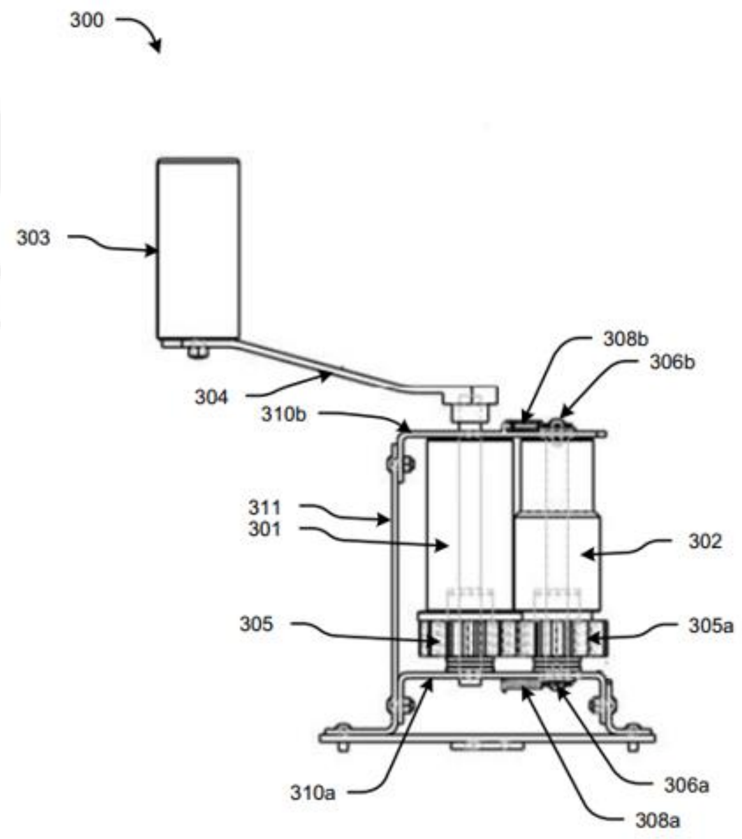


Figure 5.18: Roller assembly (part details). (Source: author)

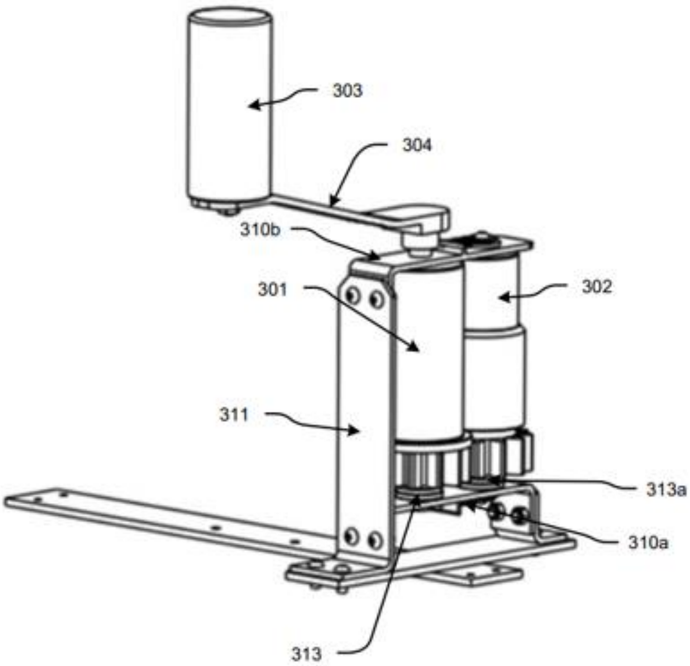


Figure 5.19: Roller assembly (part details). (Source: author)

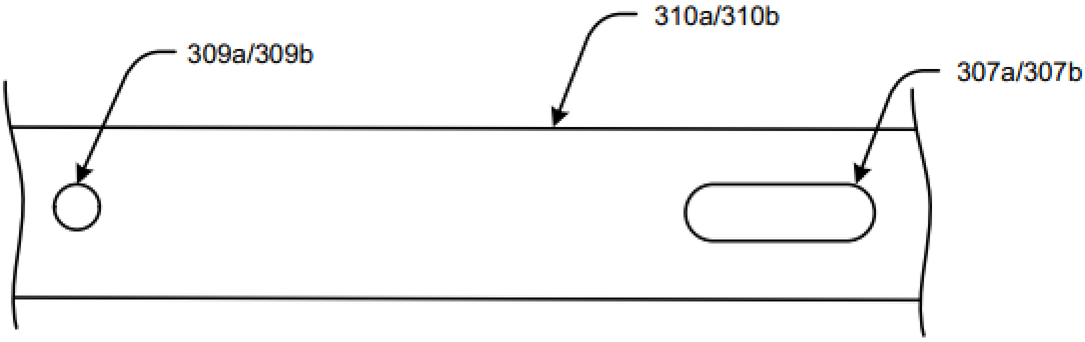


Figure 5.20: Roller assembly (part details). (Source: author)

Referring to the above Figures 5.17- 5.20, Figures 5.17-5.19 illustrate different views of a roller assembly of the innovative pouch/ sachet cutter, and Figure 5.20 illustrates an exemplary top view of lower / upper horizontal plates showing roller gap adjusting slots for accommodating sachets of different thicknesses.

The above figures illustrate different views of a roller assembly (300) of the pouch/ sachet cutter and constituent parts, which includes a pair of rollers (301 and 302) of the same height. The rollers are made of plastic material, such as Acrylonitrile Butadiene Styrene (ABS) plastic. One of the two rollers, roller (301), is a straight roller, and the other roller (302) is a stepped roller with an upper part being of lesser diameter as compared to the straight roller (301) and the lower part having the same diameter as the straight roller (301). The smaller diameter of the stepped roller (302) is configured to facilitate ease of initial loading of the stack of multiple strips of the pouches/ sachets between the rollers (before the rollers 301/ 302 are rotated for pulling of the pouches). A handle is coupled to the upper end of the straight roller (301). The handle includes a lever arm (304) and a soft rubber grip (303) fitted at a free end of the lever arm (304). A set of spur gears (305 and 305a) are provided at the lower ends of the rollers (301/ 302), in mesh with each other, such that rotation of the straight roller (301) by the handle results in rotation of the stepped roller (302) in the opposite direction. The spur gears (305/ 305a) are made up of ABS plastic.

The rollers (301/ 302) and the gears (305/ 305a) are supported on a supporting stainless-steel frame/ plates, which include horizontal plates /members, such as the lower horizontal plate (310a) and upper horizontal plate (310b), and vertical plate/ member (311). To enable smooth movement of the rollers (301/ 302), thrust bearings (313 and 313a) are provided beneath the spur gears (305 and 305a). The entire roller assembly (300) can further be integrated into the other assemblies of the pouch/ sachet cutter (100) using an integrating plate (312).

The lower and upper ends of the stepped roller (302) can be fixed to the frame through dome nuts (306a and 306b), respectively. The frame includes roller gap adjusting slots (307a/ 307b) (hereinafter, the two slots collectively referred to as slots 307) at the lower and upper horizontal plates (310a /310b), as shown in Figure 5.20, for holding the stepped roller (302), through which gap between the rollers (301/302) can get adjusted to accommodate different thicknesses of the inserted strips of pouch/ sachet or stacks thereof. Figure 5.20 also shows holes (309a/ 309b) (hereinafter, the two holes collectively referred to as holes 309) in the lower and upper horizontal plate (310a/ 310b) for fixing the straight roller (301). The straight roller (301) fixed to the lower and upper horizontal plates (310a/ 310b) through holes (309) remains fixed in a position defined by holes (309). A set of tension springs (308a /308b) are provided with the dome nuts (306a/ 306b) for providing biasing force for the movement of the stepped roller (302) towards the straight roller (301) when the thickness of the pouches is less. Thus, the gap between the rollers (301/ 302) can increase and decrease depending on requirements within the limit provided by the roller gap adjusting slot (307).

From the above-discussed constructional details, it is evident that the multiple pouch/ sachet strips (those are cut through a cutter/ blade fitted within cutting and sliding assembly) pass through the rollers and get squeezed, and the liquid content (hair oil) is extracted out of them. The gap between the rollers contracts/ expands as per need (thickness of inserted pouch/ sachet strip) through its gap-adjusting mechanism as described above.

Container assembly

Figure 5.21 illustrates the different views of the container assembly of the pouch/ sachet cutter, along with its various subparts. Figure 5.21 illustrates a perspective view of the container assembly (400) of the innovative pouch/ sachet cutter (100). The container assembly (400) includes a hollow container (401), which is cylindrical in shape and made of stainless steel, to collect the extracted contents of the pouches/ sachets. Container (401) includes a pair of two cut openings (402 and 403) (also referred to as recesses hereinafter) at the upper end of the circumference of container (401), which can be located diametrically opposite to each other and aligned with the cutting and sliding assembly (200) and the roller assembly (300) when the two are mounted within the container (401). The alignment enables the recesses (402/ 403) to function as entry and exit points, respectively, for the sachets/ pouches that are fed to the pouch/ sachet cutter (100) and provide ease of loading of the defective pouch/ sachets.

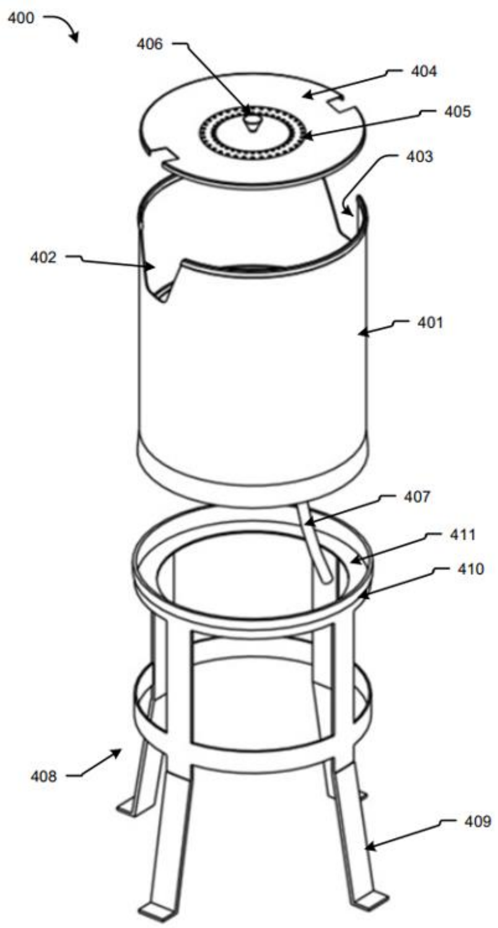


Figure 5.21: Container assembly (part details). (Source: author)

The integrating plate (312) (Figure 5.17) of the roller assembly (300) is fixed within the container (401) across a diameter of the container (401) between the recesses (402/ 403) for mounting the cutting and slide assembly (200) and roller assembly (300). A perforated plate (404) with holes (405) is provided below the integrating plate (312) within the container (401) to collect the extracted contents from the squeezed pouch/ sachets. The perforated plate (404) has a raised outer surface towards its outer circumference. It has a steep slope towards the holes (405) located near the center of the plate to maintain downward flow within the container (401). The perforated plate (404) is held within the container (401) along its circumference by suitable supports provided on the inner side of the container (401).

A holder knob (406) is provided at the center of the perforated plate (404) for easy removal for cleaning and maintenance of the container (401). A drain pipe (407) is attached at the bottom of the container (401) that can be further connected to a bigger reservoir/ collection drum (not shown here) to collect the extracted contents, such as for further reuse. The container (401) rests over a stand (408), having a plurality of legs (409). The support surface of the stand (408) that supports the container (401) includes rubber grips (411) located within an inner circumference of the upper portion (410) of the stand (408) to provide a tight grip and avoid metal-to-metal contact, thereby protecting against corrosion and friction sound.

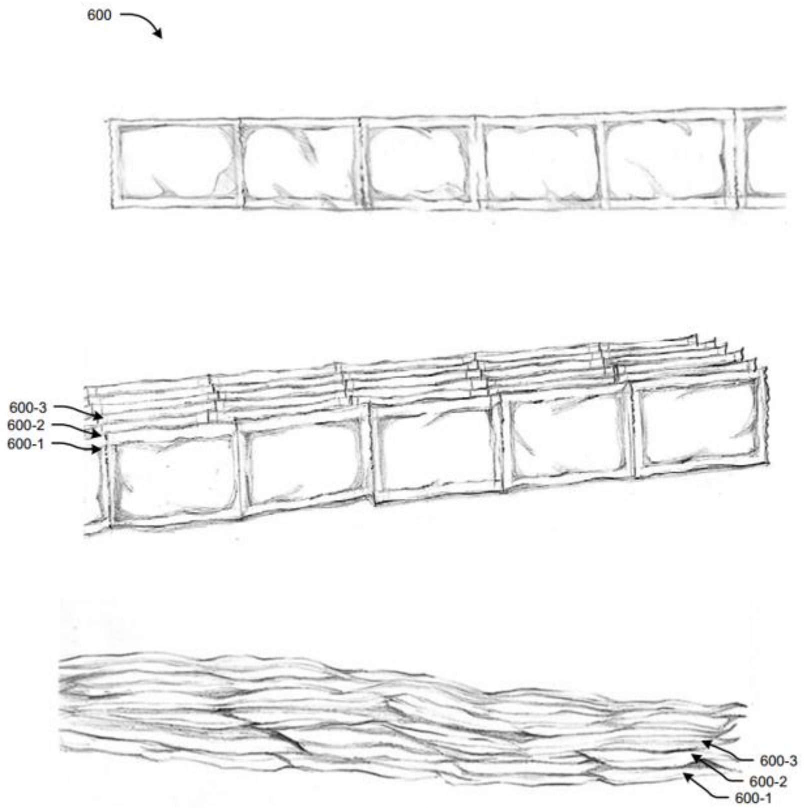


Figure 5.22: Representative sketches of strips of pouches and stacks of pouches. (Source: author)

From the above details of all three assemblies, the working of the innovative pouch/ sachet cutter is clear and understandable. However, a brief working of this pouch/ sachet is described in brief in the following paragraphs. Figure 5.22 illustrates the representative sketches of strips of pouches and stacks of pouches that can be processed/ reworked through the present innovative pouch/ sachet cutter. It shows the representative sketches of strips (600) of pouches and stacks of strips of pouches, comprising strips 600-1, 600-2, 600-3…….etc., that can be processed through this innovative pouch/ sachet cutter. As shown, strips (600) and the stacks of strips of the pouches shall have different thicknesses. The pouch/ sachet cutter (100) includes features that allow for accommodating such variations by adjusting the width of the feeder channel (211) of the cutting and sliding assembly (20), as well as in the roller assembly (300). (refer to the above sections).

While in application the strips of pouches, such as strip (600) shown in Figure 5.22, either individually or in stacks, such as stacks comprising strips (600-1, 600-2, 600-3…….etc., can be manually inserted in the feeder channel (211) through the recess (402) in the container (401) and moved along the longitudinal direction of the cutting and sliding assembly (200) within the feeder channel (211). The movement shall result in the cutting of the pouches by the cutting blade held by the cutting and sliding assembly (200). A leading end of the strip/ stack of the strips can be engaged between the rollers (301/ 302) and the rollers rotated by the handle, on which the rollers shall pull the remaining strip through the cutting and sliding assembly (200), and simultaneously squeeze the pouches to extract the contents. The squeezed content is collected in the container (401) and transferred to the main reservoir for further reuse.

5.2.7 Physical prototype development

As mentioned in the previous section, various aspects of human factors (anthropometric, biomechanical, usability, etc.) were considered for physical product development while fabricating various components of the intended product with actual material to ensure the intended function and usability. Further, the physical prototype of the selected concept (number 9) was developed (Figure 5.23- 5.25). The physical prototype of the pouch/ sachet cutter developed for Factory B is shown in Figure 5.23- 5.25. Figure 5.25 illustrates the various assemblies of the innovative pouch/ sachet cutter in a close-up view. The detailed drafting of this product is given in Appendix A.7 (measurements in mm).

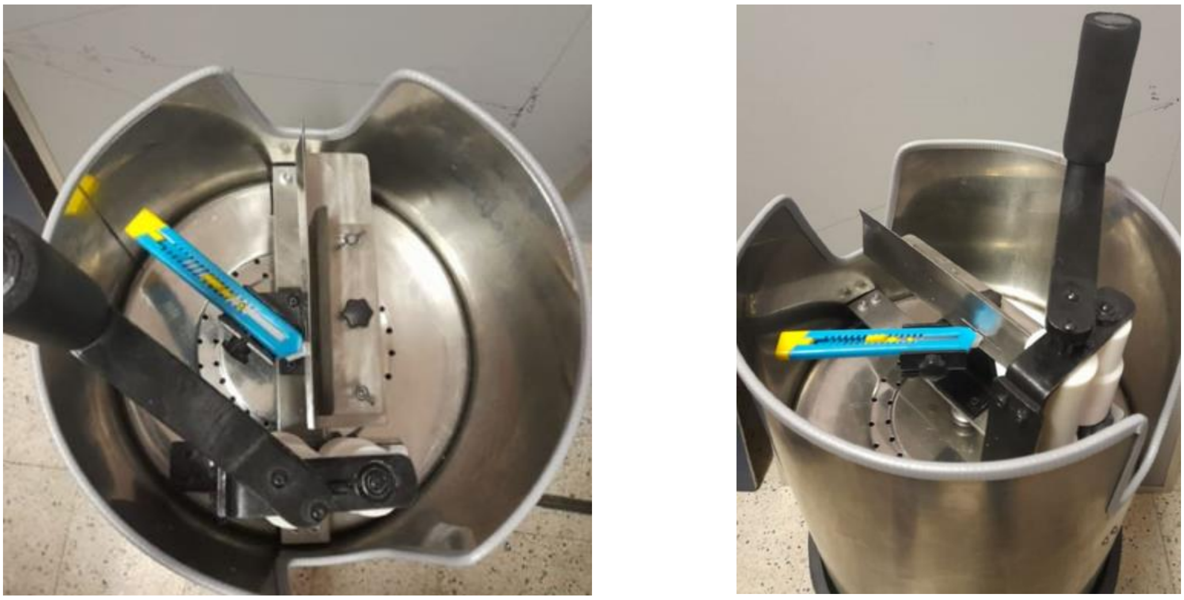
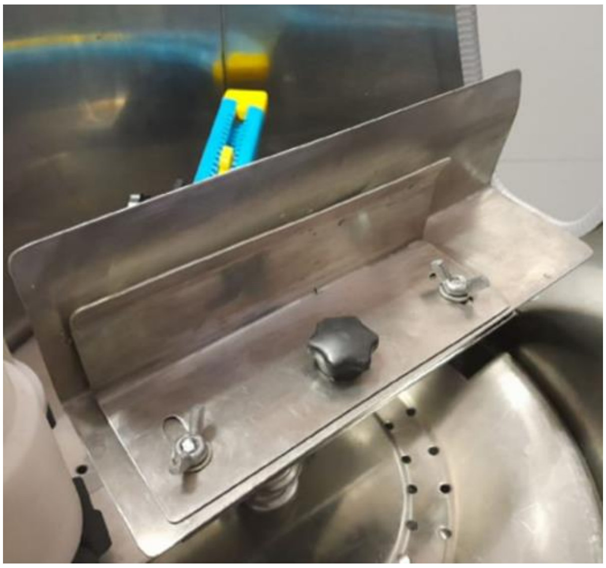


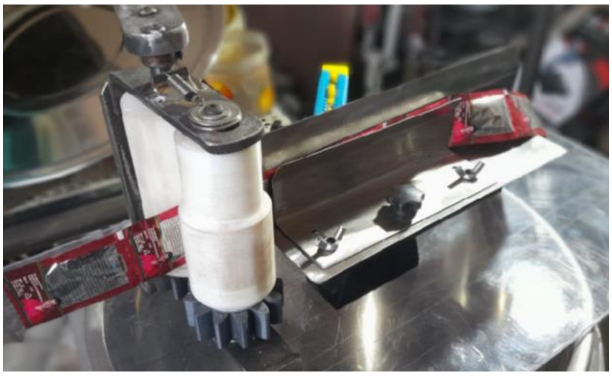
Figure 5.23: Pouch/ sachet cutter (physical prototype developed). (Source: author)

a b c

Figure 5.24: Pouch/ sachet cutter (physical prototype) (various views). (Source: author)



a b



c d

Figure 5.25: Pouch/ sachet cutter (physical prototype) (various assemblies). (Source: author)

Figure 5.25 a illustrates the cutter and slide assembly (200). Figure 5.25 b illustrates the roller assembly (300), while Figure 5.25 c shows a pouch/ sachet strip gripped/ squeezed within the roller assembly (300). Figure 5.25 d depicts the stand (408) of the innovative pouch/ sachet cutter developed for Factory B.

5.2.8 Factory trials

Once the apparatus's physical prototype was ready, the field trials were carried out at Factory B to understand the product's functionality and related consequences/ insights (Figure 5.26). Seven workers were engaged for factory trials, and data regarding productivity (number of pouches cut) and other physiological/ anthro-biomechanical parameters were taken to understand the exertion levels of workers while using the developed product. Data regarding usability was also gathered. Table 5.4 summarizes testing variables (physiological and anthro-biomechanical, production, usability) (n) = 7. To determine the product's potential success, various parameters of success were considered/ adopted, including performance improvements, physical/ cognitive ease, and easy adaptability (refer to Chapter 4, section 4.2.8.1 to 4.2.8.4) as considered for the innovative pouch/ sachet cutter developed for Factory A.

Figure 5.26: Field trials at Factory B. (Source: author)

Table 5.4: Factory Trials - Insights (Summary)

1. Productivity:

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
Number of pouches reworked per 15 min (average of 3 trials)	475 ± 12 pouches/ 15 minutes	2340 ± 49 pouches/ 15 minutes

2. Human Factors:

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
Physical exertion level measured utilizing Heart Rate	Resting/ before the start of the work: 81 ± 14 bpm After 2 hrs of work 87 ± 12 bpm	Resting/ before the start of the work: 80 ± 15 bpm After 2 hrs of work 83 ± 8 beats/minute
The muscular effort required and, therefore, fatigue level measured utilizing handgrip strength dynamometer (Make: Jamar & Model: J00105)	Resting/ before the start of the work Right: 39.5 ± 6.5 kg Left: 38.9 ± 5.2 kg After 2 hrs of work Right: 29.9 ± 8.7 kg Left: 30.4 ± 3.8 kg	Resting/ before the start of the work Right: 40.4 ± 4.9 kg Left: 39.8 ± 6.4 kg After 2 hrs of work Right: 37.4 ± 4.6 kg Left: 39.1 ± 3.1 kg
Cognitive workload measured using NASA-TLX questionnaire (MWW)	74.47 ± 11	33.9 ± 18

3. Wrist Posture:

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
Wrist Posture	Variable (no fixed posture)	Neutral

4. System Usability Scale (SUS):

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
SUS Score	(not conducted)	85 (Excellent)

The field trials depicted that the newly developed innovative safety-enriched pouch/ sachet cutter was more productive and easier to use. It was well-received by the workers and factory management.

5.3. Discussion

The current product design/ development process followed in this research for factory B's innovative pouch/ sachet cutter provides several vital insights describing the peculiarity, vitality, rigor, and fundamental anchoring of the concepts theoretically and in application. These insights are discussed in detail in the coming subsections.

Insights from the field survey

The preliminary ergo-audit conducted (Singh and Karmakar, 2022) on the shopfloor of Factory B, located in Assam, India, revealed that this factory employs a large number of employees as compared to Factory A and is more automated. Its production scale is of the order of medium-scale production units (large sector). However, the rework activity in Factory B is done manually, engaging casual labor that reworks almost 0.2 million pouches/ sachets in a day. As the work demand of rework activity in this factory is higher, the innovative cutter developed for Factory A was unsuitable to cater to the work demand of the workers/ factory management of this factory. Subsequently, their specific work parameters and needs/ requirements were assessed, and the design and development of context-specific innovative pouch/ sachet cutter for them was sought.

Insights from the product design phase

The product design and development process, which comprised concept generation, concept screening, virtual prototype development, physical prototype development, and field trials, was deployed for the innovative pouch/ sachet cutter for Factory A (refer to Chapter 4). In this chapter, specific to the design/ development of the pouch/ sachet cutter for Factory B (the representative of the medium-scale production unit working under a large sector); as the need/ requirement varied, the concepts generated varied in terms of shape, construction, product architecture, etc. A total of ten concepts were generated using a Morphological chart (Norris, 1963; Verma and Karmakar, 2021; Singh and Karmakar, 2024) and by deploying the Pugh chart (Pugh, 1991; Lin and Hsiao, 2019; Wu and Hsiao, 2019, Singh and Karmakar, 2024), the best concept was selected, and a virtual prototype of that was developed. Further, the physical prototype of the chosen concept was developed.

Careful consideration of anthropometric and biomechanical parameters has been incorporated while designing and developing the present 'pouch/ sachet cutter.' Various anthropometric parameters, like elbow height, handbreadth (without thumb), grip inside diameter, etc., (Chakrabarti, 1997) were considered for designing the various product features/ dimensions while developing the virtual model of the product. These anthropometric landmarks were considered for the optimal population percentile as per the needs and requirements of the intended workers of Factory B. Table 5.5 depicts a few of such anthropometric considerations used in the design phase.

Table 5.5: Anthropometric considerations used in the design phase. (Source: author)

Sr. No.	Parameter/ Feature Considered	Anthropometric Landmark Considered	Population Percentile Considered	Dimension (mm)
1.	Handle height	Elbow height (standing and erect)	50^{th} percentile combined data (male-female population)	1020 mm
2.	Handle length (vertical height)	Handbreadth + allowance (without thumb)	95^{th} percentile (male population)	(90 + 10) mm = 100 mm
3.	Grip diameter	Grip inside diameter	25^{th} percentile (female population)	42 mm
4.	Container radius	Olecranon to Stylion length + Hand grip length (less than this)	5^{th} percentile (female population)	(192 + 41) mm = 233 mm

In addition, the handle arm length was suitably decided to let the worker comfortably work using the present apparatus. It was decided in such a manner that the distant point of handle sweep should come within the forward arm grip reach, and the worker should not be compelled to lean his body forward to rotate the roller handle.

Similarly, several biomechanical considerations were carefully thought of while designing the product to keep the wrist posture in the neutral position so that no Ulnar or Radial (lateral or medial) deviation of the wrist occurs while using the intended product. In addition, various ergonomic principles of hand tool design were also considered. The biomechanical features considered in this design phase are as follows:

- To ensure the neutral wrist posture (no lateral or medial bending), the location of the handle from the ground has been optimally decided to accommodate varying elbow-wrist heights.
- Ergonomic principles of hand tool design were considered during the concept development, viz., handgrip strength, grip diameter, wrist posture, handbreadth, etc.
- Rubberized material for the handle was used/ given to reduce contact pressure between the palm and handle surface.

This adopted method of selecting anthropometric and biomechanical parameters for product development is in corroboration with other innovative product development studies (Sanjog and Karmakar, 2019; Verma and Karmakar, 2021; Singh and Karmakar, 2024).

The fully functional innovative product, a safety-enriched pouch/ sachet cutter, was developed using thoroughly explored design and ergonomics principles. It was further taken for field trials at Factory B to assess its functionality, performance, and user acceptance. The following subsection discusses the key insights gathered from the factory trials.

Factory trial phase

Post-development of the physical prototype of the safety-enriched cutter, the field trials at Factory B were conducted to evaluate several essential parameters deemed fit for its performance analysis and user acceptance level assessment. Table 5.4 summarizes the observations/ results of these specific parameters for the existing and improved scenarios (using a newly developed safety cutter). This comparison provides vital information and insights about the products's level of success and other relevant concerns.

The number of pouches reworked using the existing method and with improved cutter were taken into account to determine the productivity levels. Trials for 15 minutes were recorded for each worker, and three such trials were taken. The average of three trials was used for reporting purposes. It revealed that the existing method, wherein the pouch/ sachet cutting was done using a sharp cutter/ blade held in bare, slippery hands, and hand squeezing was carried out, and the workers were able to cut on average 475 ± 12 pouches. However, with the use of a newly developed safety cutter capable of cutting and squeezing multiple strips at a time, the average number of pouches/ sachets reworked rose to 2340 ± 49 per 15 minutes. This was attributed to the capability of the present innovative cutter to rework multiple pouches/ strips at a time. It was a significant improvement in the context of productivity levels and efficiency. It can be attributed to the fact that while using the newly developed cutter, the workers were not forced to be more cautious (about cuts/ injuries happening while operating) while using the safety-enriched cutter wherein the blade was held in the dedicated cutter-holding frame and eliminated the need to hold sharp cutter/ blade in bare slippery hands. They were able to perform swiftly as the cutter/ blade held in the frame and cutting the inward moving pouch/ sachet strips eliminated the inherent feeling of danger that was an integral part of the earlier process, wherein the cutter/ blade was held in the bare, slippery hands and was prone to minor accidents and injuries. Moreover, productivity rose as the newly developed cutter eliminated the need for manual squeezing (now roller squeezing was easily operable), thus making the task fast and eliminating the chances of contamination.

For an assessment of the product's compatibility with the job/ activity, tool-worker interface, and related consequences, the human factor evaluation based on physical exertion level using heart rate, fatigue level measurement using handgrip strength, and cognitive load assessment using NASA-TLX was performed for the existing and improved scenarios was conducted.

Physical exertion level was measured utilizing the Heart Rate. Heart Rate was taken for each worker in the resting state, i.e., before the start of the work and after 2 hours of work. For the existing scenario, the Heart Rate before the start of work was 81 ± 14 beats/ minute (bpm) and was 87 ± 12 bpm after 2 hours of work. While using the newly operated pouch/ sachet cutter, these values were 80 ± 15 bpm and 83 ± 8 bpm, respectively. From these values, it is evident that there is no major deviation in physical exertion levels while operating with the newly developed cutter. The exertion levels in both scenarios are almost in line with each other; rather, in the improved scenario, the Heart Rate values were lower at the end of the 2 hours of work. It can be concluded from the facts that the newly developed cutter is easy to operate and handle and does not exert much physical exertion on the workers, as ascertained from the Heart Rate values recorded.

The handgrip strength values measured the muscular effort required to perform the rework job/ activity and the induced fatigue. In existing scenarios, the recorded values for the resting/ before the start of the work were 39.5 ± 6.5 kg and 38.9 ± 5.2 kg for the right and left hand. The obtained values for the handgrip strength after the 2 hours of work were 29.9 ± 8.7 kg for the right hand and 30.4 ± 3.8 kg for the left hand. For the improved scenario, wherein the need for manual hand squeezing was eliminated, the obtained values were 40.4 ± 4.9 kg for the right hand and 39.8 ± 6.4 kg for the left hand at the resting state (before the start of the work). At the end of 2 hours of work, the obtained values were 37.4 ± 4.6 kg and 39.1 ± 3.1 kg for right and left hand, respectively. These values show that the decrease in handgrip strength is lower in the improved scenario than in the existing scenario. It can be interpreted that using a newly developed cutter capable of auto-squeezing (by its integrated vertical rollers) helps minimize the fatigue induced by manual hand squeezing. A lot of workers' effort to manually squeeze liquid from cut pouches/ sachets is saved using the newly developed cutter. Moreover, it eliminates the chances of contamination that may occur due to liquid contents touching hands. Thus, this newly developed cutter reduces drudgery.

Cognitive Load Measurements were done by administering the NASA-TLX questionnaire and calculating the overall MWW. The obtained MWW value for the existing scenario was 74.47 ± 11, an indicator of the high cognitive workload associated with the rework activity being carried out in the existing scenario wherein the sharp cutter/ blade is held in bare, slippery hands, and manual hand squeezing was required. In such a scenario, workers must remain cautious, work slowly, and exert high manual effort (for squeezing) to perform their rework task without any standardized/ context-specific tool/ apparatus. These factors account for the higher cognitive workload as indicated by the obtained overall MWW values. However, as a newly developed safety cutter eliminates the need to hold the cutter/ blade directly in the hand and subsequent hand-squeezing, the cognitive load decreases, as indicated by the obtained MWW value of 33.9 ± 18. Hence, it is evident that the present innovative ergonomic design intervention is capable of reducing the perceived physical and cognitive demand and effort among the workers engaged in rework activity.

Biomechanical posture compatibility evaluation for the newly developed cutter was assessed by minutely observing the 'Wrist' posture while performing the rework activity in an improved scenario. The wrist was mainly used to hold and move the present innovative pouch/ sachet cutter's roller assembly via the hand holding a well-gripped handle. So, for compatibility of the highest concern, keen observation of the probable use of the wrist while performing the job/ activity was considered. It was observed that the 'Wrist' remained in a 'Neutral' position while performing this task. It was also observed that:

- There was no lateral or medial bending, and the wrist remained neutral. Moreover, there was no movement of the pivot joint between the radius and ulna bone; therefore, there was no pronation or supination at the palm.

These observations confirmed the biomechanical posture compatibility of the newly developed cutter for this rework activity. It assures that the newly developed cutter can be used with ease, will not cause any harm while being used, and is perfectly adaptable to the needs of the rework activity. No such evaluation was possible in the existing scenario as no standard way of working exists. Workers tend to work in variable postures, particularly involving the wrist. The newly developed cutter provides a standard context-specific tool for rework activity and a standard way of working using the same. It is a major shift from a non-standardized activity towards standardization achieved via a context-specific innovative tool/ apparatus design and development approach.

User acceptance (usability evaluation) of the newly developed cutter was measured by administering the SUS questionnaire. A SUS score of 85 was obtained, depicting an 'Excellent' and 'Acceptable' usability rating, according to the adjectives shown in Table 5.6. The respondents rated for the 'positively phrased' and 'negatively phrased' questions while responding to the requirements of the SUS questionnaire. It was observed that, for odd-numbered questions (positively phrased), the responses were mostly 'agree' and 'strongly agree'; in contrast to even-numbered questions (negatively phrased), high response percentages were mostly between 'disagree' and 'strongly disagree.' As a result, an overall SUS score of 85 was obtained. It reflects the wide acceptability of the newly developed tool/ apparatus among the intended users and its success. They expressed their readiness to adapt to the newly developed innovative tool. No such evaluation was done in the existing scenario, as no new tool/ apparatus existed for assessment.

Table 5.6: SUS score and associated rating and interpretation. (Source. Brooke, 1996)

SUS Score	Adjective Rating	Acceptability
89-100	Best Imaginable	Acceptable
84-88	Excellent	
71-83	Good/ Very Good	
50-70	OK	Marginal
32-49	Poor	Unacceptable
20-31	Awful	
0-19	Worst Imaginable	

5.4 Developmental Cost

The physical prototype of the newly developed safety-enriched pouch/ sachet cutter was developed for factory trials. The representative cost for fabricating a single piece of such a prototype is depicted in Table 5.7.

Table 5.7: Representative cost for fabricating a single piece (prototype). (Source: author)

Cost Head/ Description	Cost (in USD)
Raw material	205
Fabrication charges	220
Miscellaneous charges	50
Total cost for one prototype	475

This cost is for fabricating a single prototype for factory trial. It is expected that the price of the final product (commercially available product) will be reduced to a great extent when mass manufacturing of such products is done.

5.5 Conclusion

The current chapter (Chapter 5) describes in detail the systematic user-centered product design approach followed for the design and development of a safety-enriched pouch/ sachet cutter for Factory B (representative of medium-scale production units), more particularly for the context-specific need/ requirements of Factory B governed by its scale of production and work parameters. Following the current research, an innovative pouch/ sachet cutter was developed, considering ergonomic and design principles. It is capable of ensuring safety in rework activity as it eliminates the need to hold a sharp cutter/ blade in bare, slippery hands. Moreover, it reduces drudgery as it eliminates the need for manual hand squeezing and perhaps helps minimize the source of contamination. This innovative tool/ apparatus, which was designed with various anthropometric and biomechanical considerations in the development phase, was well received by factory workers and management. It fulfills their specific needs associated with their work style adopted in regard to rework activity and, in conjunction, fulfills the aim of this current research at Factory B that recites 'To design and develop a safety-enriched pouch/ sachet cutter for rework activity performed in a factory with medium-scale production level. Such a pouch/ sachet cutter must be capable enough to cut 25-100 pouches/ sachets at a time and eliminate the need to hold a sharp cutter/ blade in bare, slippery hands and hand squeezing'.

Additionally, as the product is innovative and has market potential, protecting the Intellectual Property Rights (IPR) of this tool/ apparatus was deemed necessary. Utility patents and design registration were proactively secured for the present innovative pouch/ sachet cutter. Researchers have so far protected its IPR well in its parent country (India) and the United States (U.S.), and Australian patents are under examination. This particular research tried to derive various scholarly outputs from the conducted work to endorse its probable success. As it was related to innovative product design, the IPR was a major stake, and those were secured first, and journal publication is under process.

5.5.1 Scholarly outputs

Efforts were made to derive various scholarly outputs from this well-directed research conducted at Factory B. Table 5.8 below summarizes the scholarly outputs achieved from this work.

Table 5.8.: Scholarly outputs from present work. (Summary)

Component	**Details**	**Status**
Utility Patent (India)	Patent No.: IN 415999	GRANTED and In Force
Design Registration (India)	Design No.: 360578-001	GRANTED and In Force
Utility Patent (PCT)	Application No.: PCT/IB2022/056316	Published & National Phase entries made in the U.S. and Australia
Utility Patent (U.S.)	App. No.: 18/020,030	Under Examination
Utility Patent (Australia)	App. No.: 2022238038	**ACCEPTED** (Ready for GRANT)
Journal Article (SCIE)	**Title**: Ergonomic design intervention in FMCG shopfloor to address safety concerns in non-standardized work activities	**COMMUNICATED** to *International Journal of Industrial Ergonomics.*

6

Development of Pouch/ Sachet Cutter for FMCG Factory with Large-scale Production Levels

Abstract

This chapter elucidates the design and development process of the innovative pouch/ sachet cutter for the safety-enrichment of rework job/ activity in the FMCG shopfloor of a factory working at a large-scale production level (Factory C). Initially, minute observations of the rework activity were made to understand the work requirements, work posture adopted, existing work scenarios, and OSH concerns. The specific needs and requirements of the stakeholders (from the intended tool/ apparatus) were gathered through discussions. Multiple concepts of the intended tool/ apparatus were generated using a Morphological chart. Ten concepts were developed. Concept screening utilizing the various criteria finalized (based on user requirements) was done using a Pugh chart. Post-concept screening, the CAD model of the selected concept was developed to explain its operational mechanism to stakeholders. The finalized CAD model was achieved after several iterations, and a physical prototype was developed. A thorough consideration of anthropometric and biomechanical parameters was taken care of while developing the prototype. The apparatus developed was put into factory trials wherein it was evaluated for improvement of productivity and ensuring user compatibility from human factors' perspectives (physical exertion in terms of increased HR, reduction of handgrip strength, cognitive workload, etc.). Following the factory trials, the developed apparatus was found effective in mitigating safety concerns and various ergonomic stressors associated with FMCG rework at Factory C's shopfloor.

6.1 Introduction

Chapters 4 and 5 discussed in detail the design and development of innovative pouch/ sachet cutters devised per the context-specific needs of Factory A (small-scale production level) and Factory B (medium-scale production level). Those were successfully tested and validated on the shopfloor of Factory A and Factory B, respectively, wherein those were well-received by the workers and factory management of the respective factories as they met their distinct needs and requirements (refer to Chapters 4 and 5). After successful trials of the innovative pouch/ sachet cutter developed for Factory B, Factory C (a representative of the large-scale production level) was approached with the innovative product developed and its trial data results. Upon discussion with various stakeholders, it was found that this tool/ apparatus will not be able to cater to their rework needs as their work demands and parameters differ from the capabilities/ limits of the presently designed and developed safety cutter for Factory B. As such, it was decided to gather the context-specific requirements of Factory C further concerning their anticipated pouch/ sachet cutter that would probably meet their requirements. The following sections and sub-sections discuss in detail the design and development process and related insights in the purview of the innovative pouch/ sachet cutter developed for Factory C.

6.1.1 'Factory C': FMCG factory with large-scale production level

A factory unit located in Guwahati city engaged in manufacturing personal care products (hair oil, serum, cosmetics, etc.) working under a semi-automated production setup was selected for further rigorous research and for proposing an innovative design intervention for the rework activity of that factory. This production unit falls under large-scale production levels (mega sector) as it engages automation for several of its production facilities and is capital-intensive. Still, many of its production processes remain labor intensive and utilize many permanent and contractual employees. Interestingly, the reworking activity of pouches/ sachets was manual in this factory, too. Factory management revealed that since no Original Equipment Manufacturer (OEM) provides any standardized pouch/ sachet cutter, they have to rely on manual labor for this voluminous activity on their shopfloor. Since the researcher had signed an NDA with the factory management, this factory unit, for anonymity's sake, is termed 'Factory C' in the subsequent sub-sections. Factory C is representative of large-scale production levels owing to the large number of workers engaged, multiple production facilities for the same product, and the subsequent increase in production capacity.

The selected Factory C manufactures hair oil and tends to fill the manufactured hair oil in both bottles and pouches/ sachets. The majority of its manufactured hair oil was filled in pouches/ sachets. Factory C had a worker strength of more than 1200 permanent employees and still engages 250-300 casual/ contractual laborers for non-standardized work activities like loading, housekeeping, packing, rework, etc., daily. The researcher followed the same strategy (refer to Chapters 4 and 5) of having regular visits to the factory shopfloor, understanding the demographic details of workers engaged, work elements of the job under consideration, workstation features and details (existing scenario), productivity and efficiency (existing scenario), posture evaluation, associated safety concerns, and their occurrence, etc. to gain insights about the rework activity carried out at Factory C shopfloor.

6.1.2 Insights from the survey/ field observations

The field observations of the rework activity being carried out on Factory C's shopfloor revealed several insights related to production setup, work demand, risk factors, essential functions/ subfunctions to be performed, context-specific needs/ requirements from the intended innovative design intervention, etc. These are summarized below:

6.1.2.1 Production level, work process, and urge for innovative solution

Although working under a large-scale production setup, Factory C usually engages contractual labor for rework. Typically, twelve-fifteen workers are exclusively engaged in this non-standardized work activity daily and remain engaged in recovering the in-filled liquid content out of the defective pouch/ sachet that needs to be re-filled afresh in the new pouch/ sachets. They remain busy in their work for the shift of eight hours, out of which their work extends for almost seven hours per shift. Like in the previous factories A and B, they work while sitting and cut the defective pouch/ sachets by taking the long strips of the pouch/ sachet in their hand and folding them to cut several pouches/ sachets at an instance (usually five or six pouches/ sachets). Cutting of the pouch/ sachet is done with the help of a sharp cutter/ blade that is often held with bare, slippery hands. Once the adequate number of pouches/ sachets are cut, the workers then squeeze those to extract the in-filled liquid within the temporary containers/ bins. This hand-squeezing spoils their hands with liquid content, and their hands often remain drenched with the hair oil. Once it is done, they then take the next strips to repeat the cutting and squeezing task, which continues for the whole day.

Interestingly, as this factory unit has eight-hour shifts, three shifts a day, both male and female laborers are engaged in rework activity in the general shift (daytime shift). However, in the evening/ night shift, female laborers can not be engaged as per statuary laws (Section 66 (1) (b) of the Factories Act, 1948) that prohibit women employees from working at night. As such, the factory management finds it difficult to employ trained people for this pouch/ sachet rework activity, and the work efficiency in this shift decreases steeply. As the work piles up, they are forced to employ their permanent staff to engage in this tedious activity.

However, once the permanent staff is engaged in this activity, they work in different styles and stature. They engage in the rework activity in a standing position and cut the pouch/ sachets on dedicated container units provided on the shopfloor. They do not use sharp cutters/ blades; instead, they use scissors to cut the pouch/ sachet and do not squeeze the pouch/ sachets to extract the liquid content from the cut pouch/ sachets. They leave the cut pouches/ sachets overnight on the dedicated containers to pour and drain, and whatever oil is collected, they take into account for further re-filling purposes. It was observed that the production capacity of this factory unit was very high owing to multiple automated production units (filling stations) for pouch/ sachet production. The number of rejected pouches/ sachets was high and needed to be reworked daily, and the factory management struggled to address this non-standardized work activity efficiently. On average, there lies the need to rework almost 0.4 million defective pouches/ sachets daily. It was noted that Factory C has the highest production rate of pouch/ sachet production and similarly had a higher number of rejected pouch/ sachets (almost double as compared to Factory B and fourfold to Factory A) for various reasons and thus poses a need for reworking a higher number of pouch/ sachets as compared to Factory A and B.

As already discussed in Chapters 4 and 5, the factory shopfloor workers and factory management were concerned with the difficulties and risks associated with the rework activity and considered it a task of critical concern and sought help from the researchers to address the existing adverse situation and propose innovative design interventions in the form of context-specific tools/ apparatus that may improve the situation at their factory shopfloor premises. For this purpose, a similar design and development strategy (as followed for the pouch/ sachet cutter development for Factory A and B) was followed (refer to Chapters 4 and 5). However, the context-specific details of Factory C were considered while designing and developing the innovative product.

6.1.2.2 Need/ requirements from the intended solution

By means of discussions/ interviews, the specific characteristics (desired needs) of the intended innovative safety-enriched tool/ apparatus for Factory C were assessed. These are listed below:

- It may have mechanized/ semi-mechanized operation/ working
- It should be capable of cutting 250-500 pouches at a time (cutting a large number of pouches, multiple pouches/ sachets at a time)
- It should have relatively faster operation/ working
- It may have an integrated container for the collection of extracted liquid that can hold a large volume of extracted liquid

6.2 Development of Pouch/ Sachet Cutter for FMCG Factory with Large-scale Production Levels

This section describes, in detail, the design and development process followed to develop a context-specific safety-enriched tool/ apparatus for safely reworking the pouches/ sachets on the Factory C shopfloor.

6.2.1 Aim

To design and develop a safety-enriched pouch/ sachet cutter for rework activity performed in a factory with a large-scale production level. Such a pouch/ sachet cutter must be capable of cutting 250-500 pouches/ sachets at a time and eliminate the need to hold a sharp cutter/ blade in bare, slippery hands and hand squeezing.

6.2.2 Product design and development process

To carry on the current research and proceed toward fulfilling the aim of the current chapter, a design and development process engaging various ergonomic and design principles was followed and is presented in detail in the following subsections. A generic product development process (refer to Chapter 4, Section 4.2.2.1) was deployed to devise an innovative tool/ apparatus for Factory C.

6.2.3 Product development process adopted in current research

The current research (at Factory C shopfloor) adopted a similar product design approach (refer to Chapter 4, Section 4.2.3) based on well-thought design and ergonomics principles. It was broadly conducted in three phases, viz. 1) Field Survey Phase, 2) Concept Development &

Prototyping Phase, and 3) Field Trials. It employed several Human Factors (HF)/ ergonomic principles. The initial field survey (refer to Chapter 4, Section 4.2.3.1) was conducted, and context-specific work parameters for factory C were understood to design and develop innovative products for their needs/ requirements. For finalizing various sub-functions of the intended product/ tool, the insights from the factory visits and user (workers, safety managers, management) requirements were given due consideration.

6.2.4 Concept generation

A Morphological chart was used for multiple concept generation to move further with the design and development process of a safety-enriched pouch/ sachet cutter for Factory C's specific needs (refer to Chapter 4, section 4.2.4). Table 6.1 illustrates the Morphological chart used to generate the alternate concepts of the intended product.

Table 6.1: Morphological chart generated for pouch/ sachet concept generation. (Source: author)

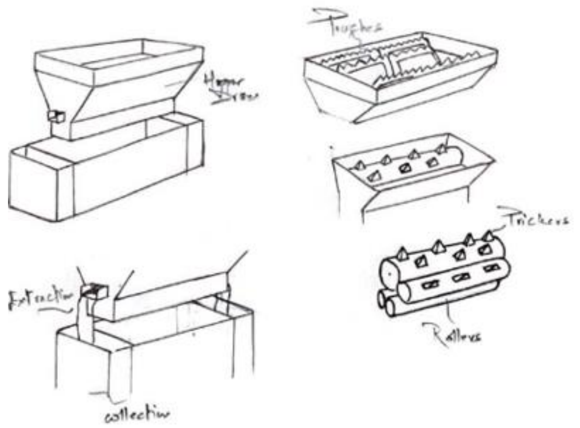
Sub Function / Solution		Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Cutting pouch to extract liquid	1	Surface Cutting	Pricking	Puncture	Scissor	Rotating Blade	Spikes
Extracting complete liquid out of cut pouch	2	Funnel Sucking	Roller Pressing	Wheel Pressing	Tapping	Block Pressing	Suction
Moving/ holding / supporting the apparatus	3	Body Frame	Vertical Frame	Between Rollers	Flap Press	Stick/ Plunger	Manual Drag/ Belt
Placing the uncut pouches	4	Guide Rail Bin	Teeth Friction	Drum Top	Direct Rubbing	Hand Held/ Belt	Cavity
Collecting the extracted liquid	5	Solid Drum Pipe	Nozzle Dripping	Direct Pipe	Bucket/ Tub/ Bin	Contact Transfer	Funnel
Feeding the incoming pouches	6	Roller Sucking	Spike Hitting	Rolling Gun	Guide Rail Feed	Manual Push	Belt/ Flat Surface
Providing energy for apparatus action	7	3 Phase Power	DC Power	Manual Effort	Electro-mechanical		

Based on inputs from the Morphological chart, the ten concepts were generated (refer to Chapter 4, Section 4.2.4) using an amalgamation matrix. Table 6.2 below depicts the amalgamation matrix of the concepts generated per the specific needs/ requirements of the anticipated innovative pouch/ sachet cutter for factory C.

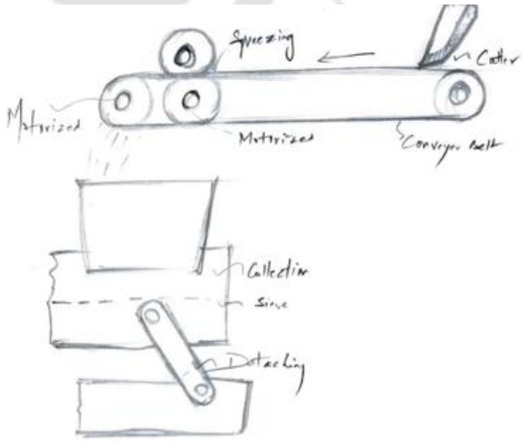
Table 6.2: Amalgamation matrix for pouch/ sachet concept generation. (Source: author)

Concept	An amalgamation of a matrix for conceptual sketch
Concept Sketch 1	(1,2) + (2,3) + (3,3) + (4,2) + (5,4) + (6,1) + (7,1)
Concept Sketch 2	(1,1) + (2,2) + (3,6) + (4,5) + (5,4) + (6,1) + (7,1)
Concept Sketch 3	(1,6) + (2,1) + (3,5) + (4,2) + (5,6) + (6,2) + (7,1)
Concept Sketch 4	(1,2) + (2,4) + (3,5) + (4,6) + (5,3) + (6,4) + (7,1)
Concept Sketch 5	(1,2) + (2,2) + (3,3) + (4,5) + (5,6) + (6,1) + (7,1)
Concept Sketch 6	(1,5) + (2,3) + (3,6) + (4,5) + (5,6) + (6,3) + (7,1)
Concept Sketch 7	(1,6) + (2,5) + (3,2) + (4,3) + (5,1) + (6,2) + (7,4)
Concept Sketch 8	(1,3) + (2,4) + (3,5) + (4,5) + (5,5) + (6,6) + (7,4)
Concept Sketch 9	(1,5) + (2,2) + (3,2) + (4,6) + (5,5) + (6,3) + (7,1)
Concept Sketch 10	(1,1) + (2,2) + (3,2) + (4,6) + (5,3) + (6,3) + (7,1)

The following ten concepts were generated as per the amalgamation matrix. A brief description of each concept is given below:



Concept 1



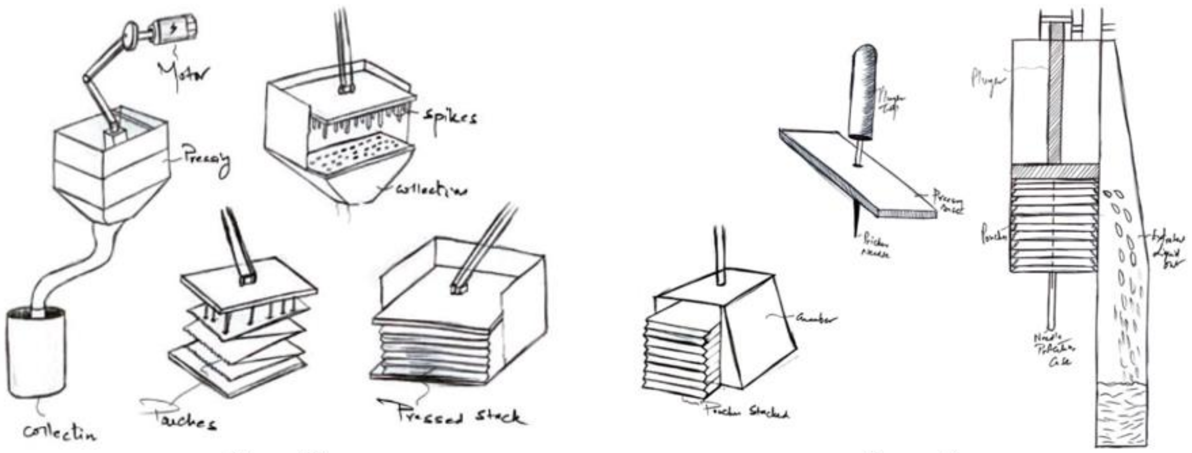
Concept 2

Figure 6.1: Different pouch/ sachet cutter concepts developed (concepts 1 and 2). (Source: author)

- **Concept 1:** This is a motorized shredding and crushing-based concept. It has a plurality of closely aligned crushing wheels with sharp teeth that engulf and prick the pouch/

sachets being fed through. Once those are pricked, the liquid content gets squeezed by getting pressed within the rotating wheels. The extracted oil is collected in a container bin that can be used at an appropriate place and attached to the crushing and squeezing chamber. A three-phase motor can be utilized to energize this apparatus.

- **Concept 2:** In this concept, a motor-powered, fast-driven conveyor belt is used to feed the pouch/ sachet strips. A cutting blade is mounted in a vertical position before the rollers at the optimal height hanging above the conveyor. Once the incoming pouch/ sachet strip strikes the blade, it gets cut, and the cut pouch/ strip further passes through the moving rollers that squeeze the liquid content out of the cut pouch/ sachets. The extracted liquid can be contained in a container attached to the designated place below the setup.

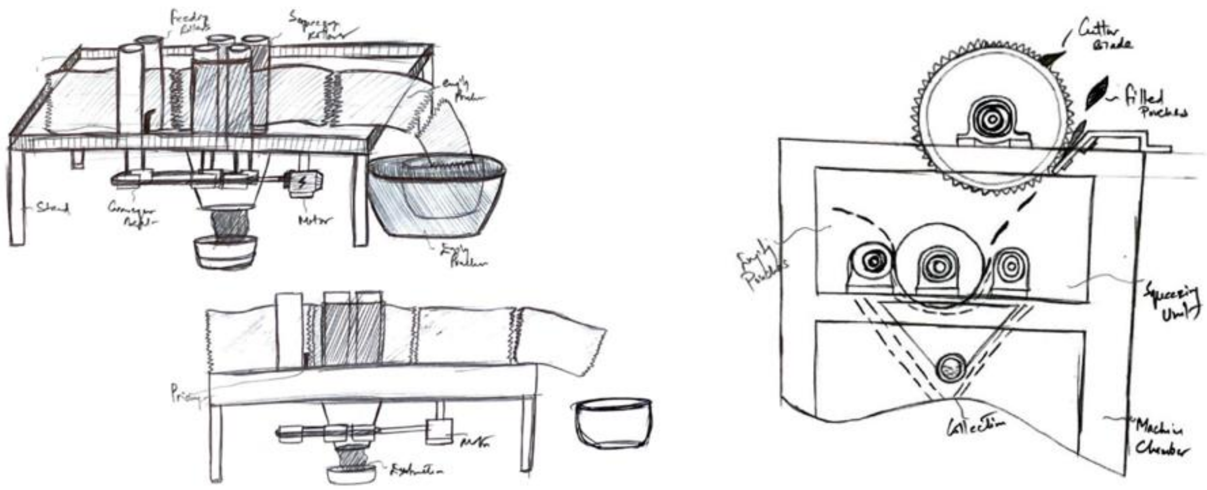


Concept 3 Concept 4

Figure 6.2: Different pouch/ sachet cutter concepts developed (concepts 3 and 4). (Source: author)

- **Concept 3:** This is a spike-hitting and funnel-sucking-based concept. It has a plunger push rod that is motor-driven and attached to a crankshaft to move up and down the spike-based flat bed provided at its bottom that is used to pierce the stack of pouches/ sachets placed inside the cutting and squeezing chamber of this apparatus. The plunger-push rod through the crankshaft can be directly pressed to pierce the pouches and by subsequent pressing the extraction of the liquid happens through the funnel mouth provided at the bottom of the pouch/ sachet cutting chamber.
- **Concept 4:** In this concept, the stack of pouches/ sachets can be loaded into the cavity chamber of this apparatus that is arranged such that on its top lies a plunger-based long needle that can prick through the placed stack of pouch/ sachets upon lowering down by

motorized operation. As the plunger-based needle pricks the pouch/ sachets, the flat-bed of the plunger presses the pricked pouch/ sachets, and the liquid content is squeezed out and passed onto the adjoining liquid collection chamber that can further be directly joined with the main reservoir through pipes or other. The cavity chamber is provided with the elongated needle-receiving fine tube that receives the needle as it lowers down by a downward moving plunger.

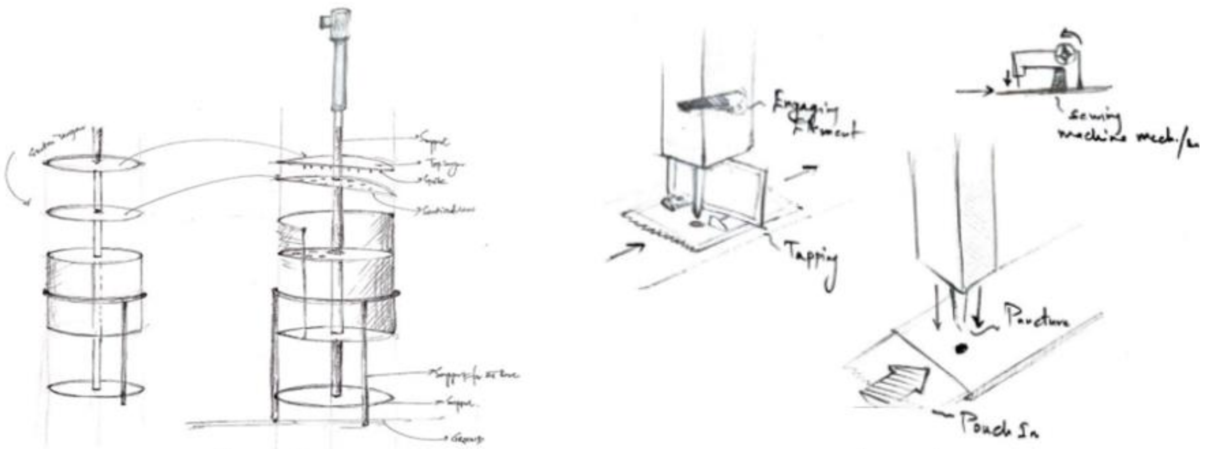


Concept 5 Concept 6

Figure 6.3: Different pouch/ sachet cutter concepts developed (concepts 5 and 6). (Source: author)

- **Concept 5:** This is a roller and conveyor-based concept wherein the vertically placed pouch/ sachet strips are fed through the receiving roller and get pricked through the sharp tapping needle placed directly next to the receiving rollers that prick the vertically placed pouches at the bottom part. As the pricked pouch/ sachet passes through the squeezing rollers, the liquid content gets squeezed and collected through the funnel-based extraction bin provided at the bottom. The empty pouches/ sachets are further collected in a trash bin. The receiving and squeezing rollers are moved on simultaneously through the motor drive belt provided at the bottom part of this setup.
- **Concept 6:** In this concept within the main chamber of this apparatus lies the squeezing unit that utilizes the closely placed rollers to squeeze the cut pouch/ sachets that come downwards after getting cut by the rotating blade placed at the top portion of the main chamber. The defective pouch/ sachet strips are fed into the rotating wheel through a rolling gun and coil-based mechanism. Once those get cut through the rotating blade, they further move downwards into the squeezing unit and get squeezed, and the extracted

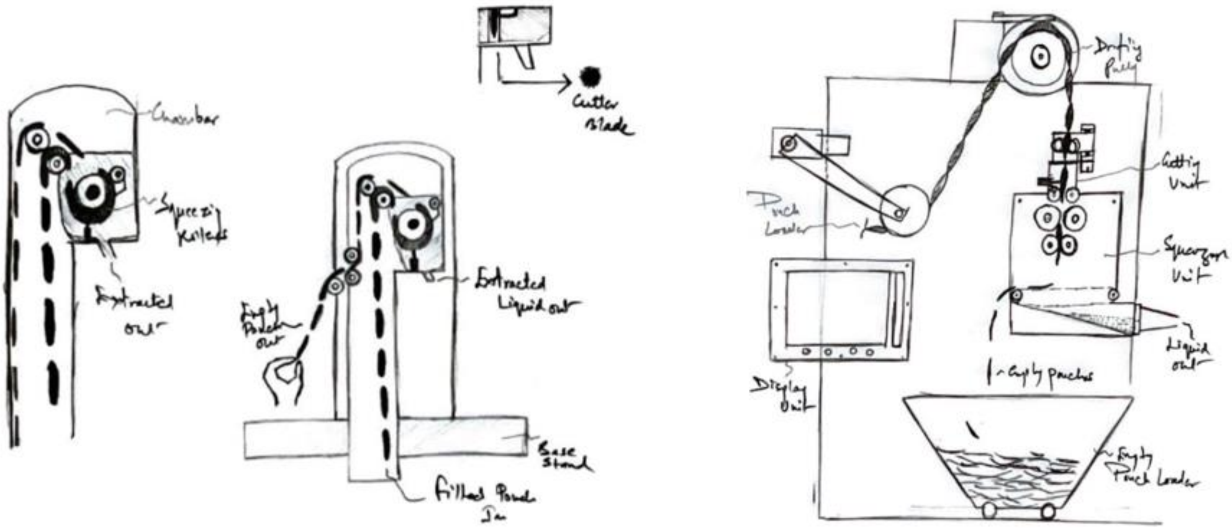
liquid content falls down and gets collected through a funnel-shaped container provided beneath. The squeezing rollers and rotating blade components are power-driven.



Concept 7 Concept 8

Figure 6.4: Different pouch/ sachet cutter concepts developed (concepts 7 and 8). (Source: author)

- **Concept 7:** This spike-hitting and tap-pressing-based concept can pierce and press the multiple pouches/ sachets placed within a dedicated chamber with the up-down movement of a circular plate containing spikes. It has an integrated collection drum, upon which the guideway containing a spike-based circular plate is mounted in the middle. The multiple defective pouches/ sachets can be randomly put into the upper base of the collection drum, and the plate containing spikes is lowered down to pierce the placed pouches. It further presses those to squeeze the pierced pouches/ sachets. The extracted liquid is collected within the integrated collection drum and can be further connected to the main reservoir. It can be power-driven by connecting its upper assembly with any pneumatic, hydraulic, or based operation. It can be manually operated by providing adequate link-bar mechanisms that enable the linear downward movement of the circular plate containing spikes within the upper base of the collection drum.
- **Concept 8:** In this concept, the incoming pouch/ sachet strips can be punctured through the needle moving up and down through a sewing-machine-based mechanism and operation. The needle puncturing at the defined slot leaves the pouch/ sachet open for further liquid extraction, which is achieved by a resisting block tapped on it through an engaging element. The resisting block tapped on the punctured pouch/ sachet strip extracts the liquid content that is further collected in a container provided adequately as per need. The guideway feeding the pouch/ sachet strip can be powered or may be manually driven as per the distinct needs of the operation.



Concept 9 **Concept 10**

Figure 6.5: Different pouch/ sachet cutter concepts developed (concept 9 and 10). (Source: author)

- **Concept 9:** This is an integrated chamber-based concept consisting of a dedicated cutting and squeezing unit provided at the top portion of the chamber. The pouch/ sachet strip is fed into the cavity compartment through a rolling gun coil mechanism that moves upwards, passes through the closely placed rollers, and enters the cutting and squeezing unit. This unit consists of a fixed rotating blade that cuts the incoming pouch/ sachet that gets elongated when it passes through the pressing roller. Once a cut is marked on the pouch/ sachet, it further passes through a squeezing roller to extract the liquid content, and the empty pouch/ sachet strip further moves out of the integrated chamber to be collected in the trash bin. The extracted liquid can be taken out to the main reservoir through any optimal means, which, at first instance, by contact transfer, gets collected within the integrated chamber.
- **Concept 10:** In this concept, the pouch/ sachet strip moves on through the loader pulley placed within the integrated chamber of this apparatus and gets lowered down into the main chamber through the drifting pulley set at the top portion of this apparatus. Once it starts moving down, it enters the cutting unit, and a cut is marked on the pouch/ sachet surface. It further passes through the squeezing unit, which is comprised of rotating rollers that squeeze the liquid content out of the pouch/ sachet. The empty pouch/ sachets are collected in a pouch/ sachet load picker placed at the bottom. A direct pipe towards the main reservoir can be placed at the exit nozzle on the chamber body's outer portion. The main chamber is provided with a display unit that helps control the functions/ subfunctions of this apparatus.

6.2.5 Concept screening

Post-concept generation, the concept screening was done utilizing the Pugh Chart (refer to Chapter 4, Section 4.2.5). Various selection/ screening criteria were finalized based on user requirements and priorities mentioned by the stakeholders (workers, safety in charge, management). In the present context, the concept '3' was chosen as the 'DATUM' or reference. Based on concept screening, concept number 7 (Figure 6.6) was selected for further development. Table 6.3 illustrates the Pugh Chart (Pugh, 1991) deployed for concept screening in the context of Factory C.

Table 6.3: Pugh chart for pouch/ sachet concept screening. (Source: author)

Selection Criteria	Weight	Concept Number									
		1	2	3	4	5	6	7	8	9	10
Safety in interacting with cutting mechanism	5	+	-		+	-	-	+	-	+	+
Efficient extraction of in-filled liquid from pouches	5	-	-		+	+	-	+	-	+	+
Provision for manual/ motorized operation	4	-	-	D	-	-	-	+	+	-	-
Ease of placing and feeding uncut pouches	4	+	-	A	+	+	+	+	+	+	+
Ease of extraction of in-filled liquid content	4	-	+		+	+	-	S	-	+	+
Ease of collection of in-filled liquid content	3	-	+	T	+	-	-	S	-	+	+
Ease of collecting/ removal of extracted pouches	3	-	+	U	-	+	+	+	+	-	+
Provision for in-house maintenance	3	-	-		-	-	-	+	+	-	-
Compactness	2	+	-	M	+	-	-	S	+	+	-
Low complexity (lesser number of mechanisms)	1	S	-		-	-	-	-	+	-	-
Cost	1	-	-		-	-	-	-	+	-	-
Weighted SUM of +		+11	+10	0	+23	+16	+7	+24	+18	+23	+24
Weighted SUM of –		-23	-25	0	-12	-19	-28	-2	-17	-12	-11
Net Value		**-12**	**-15**	**0**	**+11**	**-3**	**-21**	**+22**	**+1**	**+11**	**+13**

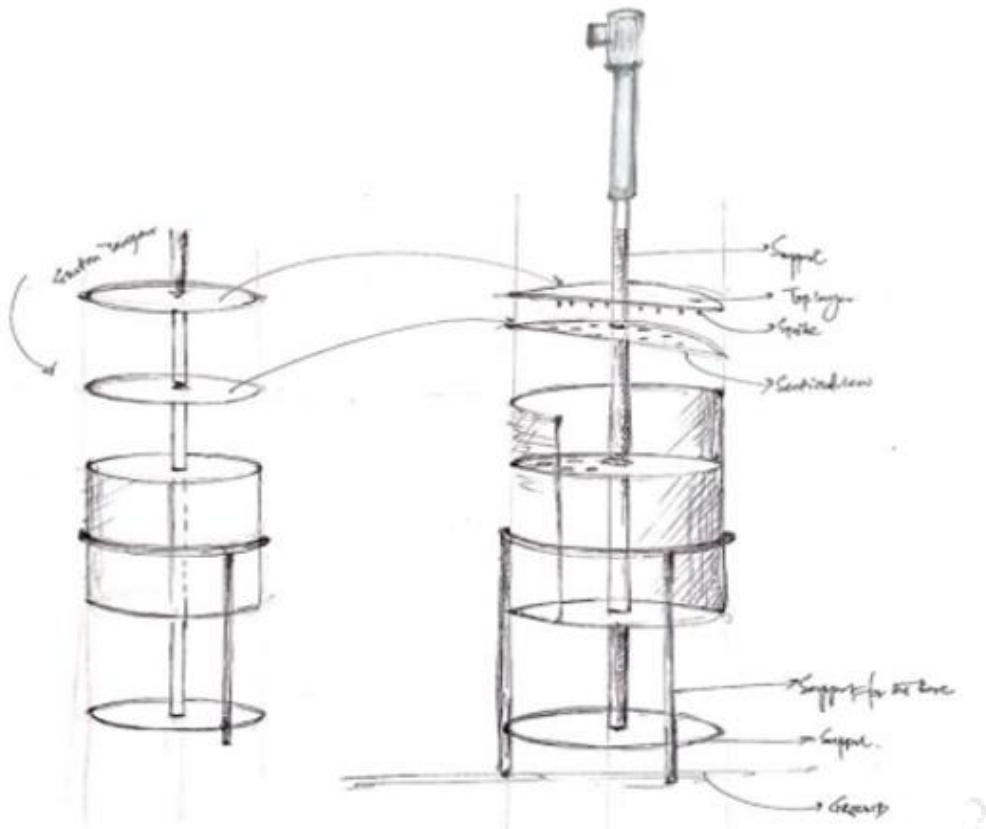


Figure 6.6: Concept selected (initial sketches). (Source: author)

6.2.6 Virtual mock-up development

Further, the CAD model development for the concept '7', the best concept conceived for safely cutting and squeezing pouches/ sachets, was taken up as the next step in the present product design and development process. The initial CAD model was shown to the stakeholders on a laptop screen, and the operational mechanism was explained to get their feedback. Following their inputs, the final iterated CAD model of the intended pouch/ sachet cutter was prepared, as shown in Figure 6.7. The exploded view and the close-up view (cutting/ piercing assembly) of the product developed in CAD are depicted in this figure, respectively.

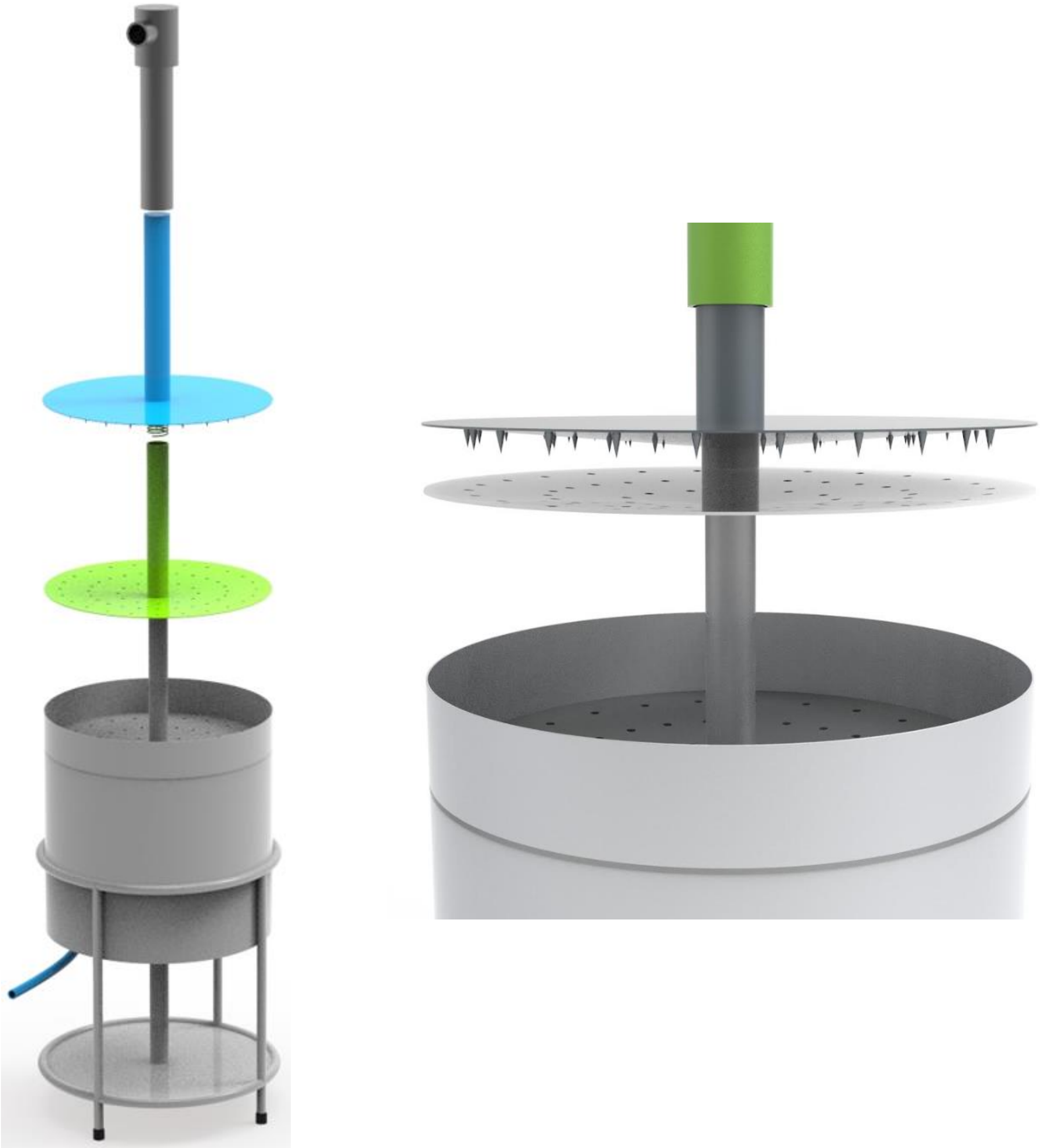


Figure 6.7: Pouch/ sachet cutter (CAD model renderings). (Source: author)

Figure 6.8: Pouch/ sachet cutter (CAD model renderings). (Source: author)

Figure 6.8 illustrates the perspective and section views of the CAD model, respectively. Various human factor principles were considered while developing the final model of the product. The anthropometric and biomechanical considerations focused on hand anthropometry, wrist's range of motion, overall posture required for using the tool/ apparatus developed, dimension of developed tools according to intended posture, and corresponding workstation, etc., were primarily considered while designing the apparatus. For the development of the tool/ apparatus, the Indian Anthropometric Database (Chakrabarti, 1997) was considered. Several parameters were considered for determining product features using different population sizes/ samples from that database. Figure 6.9 depicts the finer details of the constituent mechanisms of this innovative pouch/ sachet cutter in detail. The figure on the left illustrates the spring-based mechanism that helps move and retract the plates with spikes and another plate. The figure on the right side illustrates the plate's section view with spikes used for pouch/ sachet piercing upon downward movement within the container provided to hold the uncut pouch/ sachet.

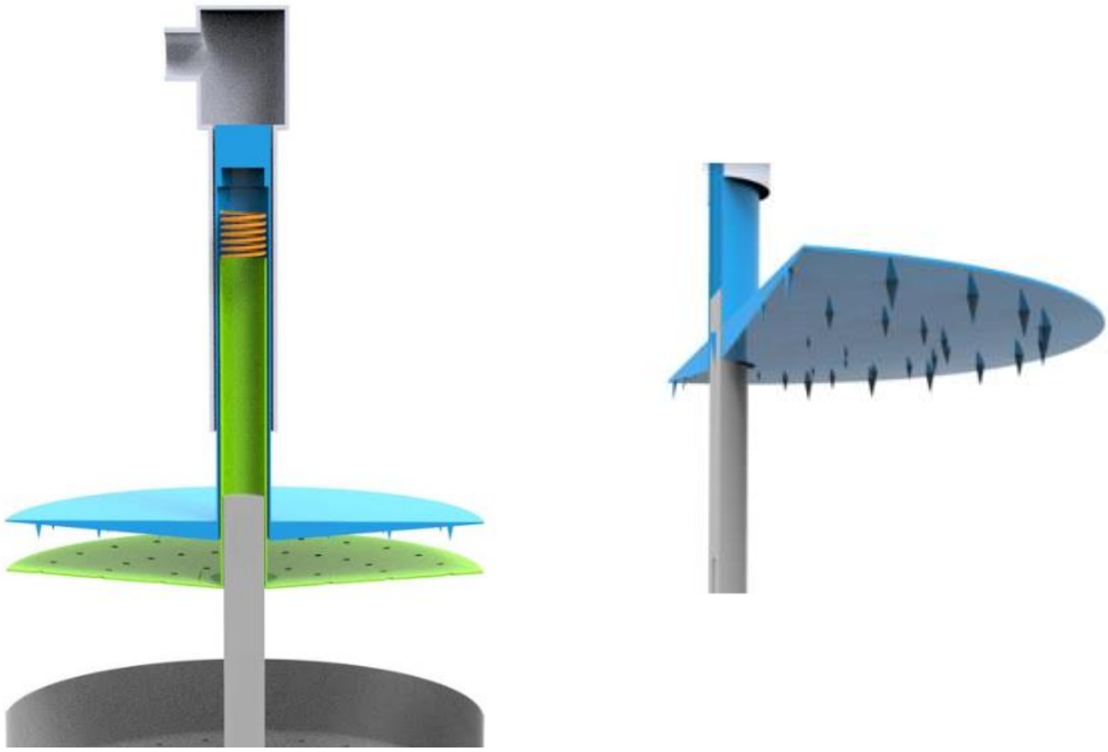


Figure 6.9: Pouch/ sachet cutter (inner component details). (Source: author)

Figure 6.10 illustrates the part details of the intended product with their functioning details. Various parts of the pouch/ sachet cutter are described in this figure to gain a preliminary understanding of the working/ operation of this pouch/ sachet cutter to be developed for Factory C.

Figures 6.11, 6.12, and 6.13 illustrate the essential part details of the pouch/ sachet cutter with part numbers. A brief working/ operation of the pouch/ sachet cutter (apparatus) is explained with the help of these part numbers in the following subsection.

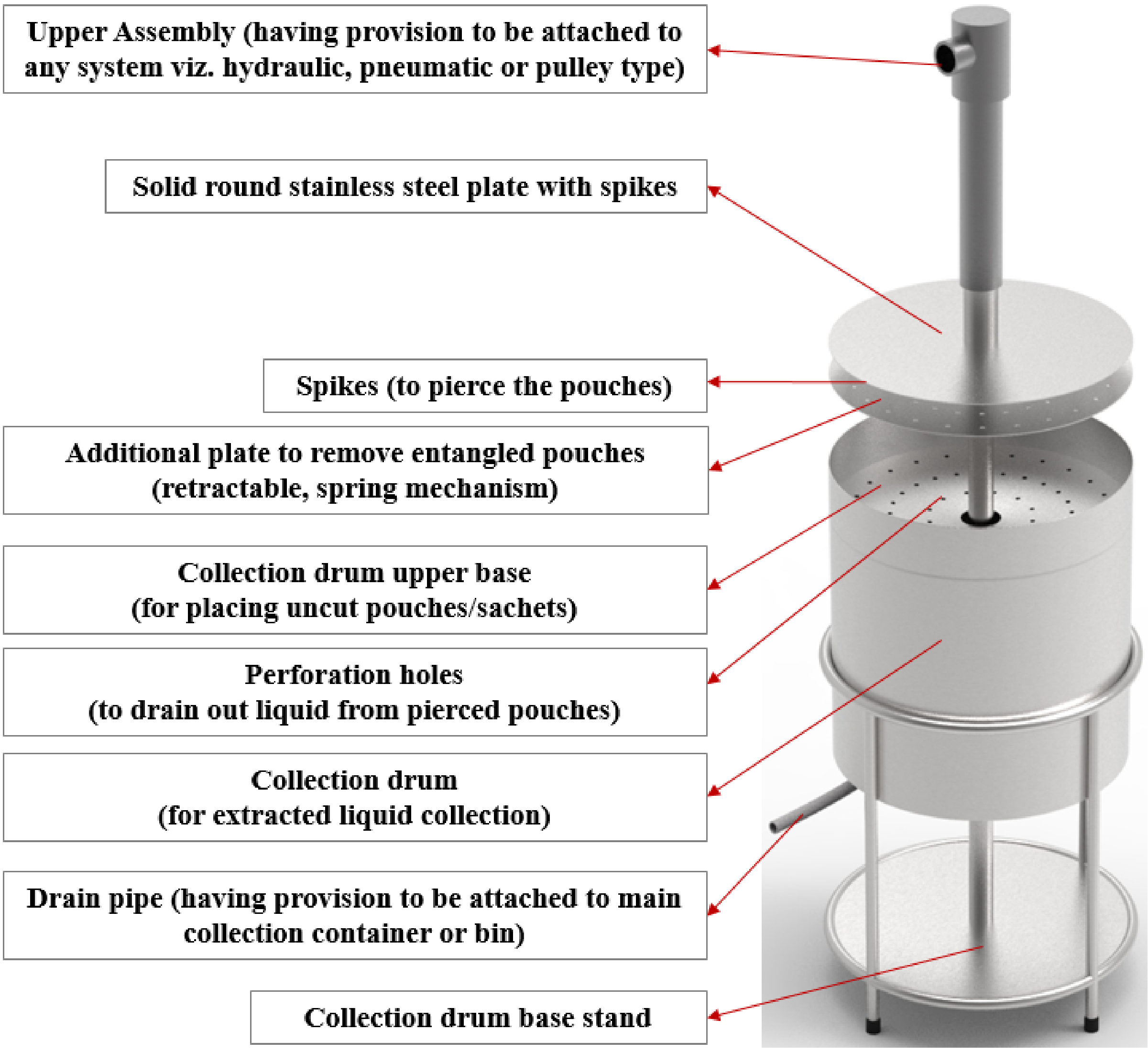


Figure 6.10: Pouch/sachet cutter (basic part details and functions). (Source: author)

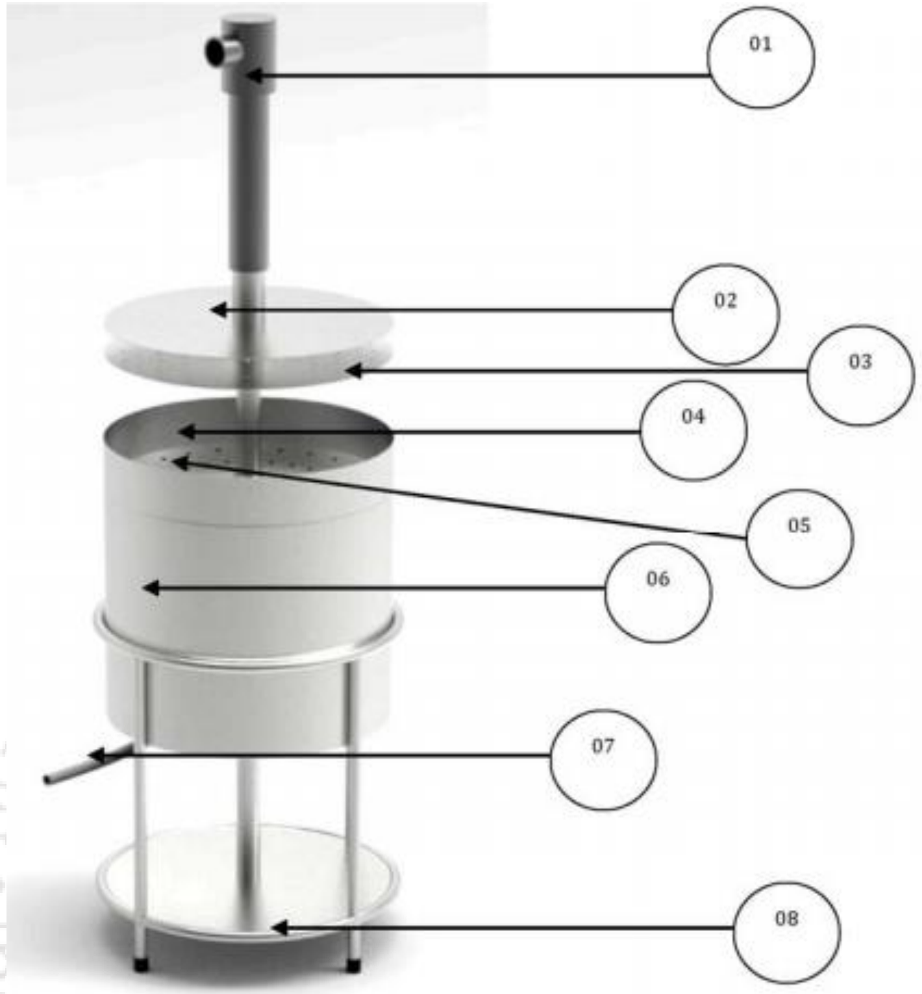


Figure 6.11: Pouch/ sachet cutter (part number and working explained). (Source: author)

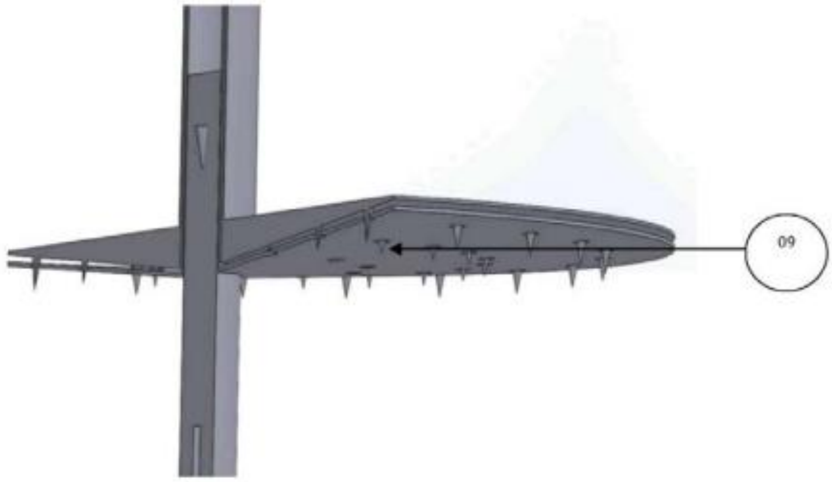


Figure 6.12: Pouch/ sachet cutter (part number and working explained). (Source: author)

Figure 6.13: Pouch/ sachet cutter (part number and working explained). (Source: author)

In this innovative apparatus for extracting the contents of a pouch/ sachet, the present apparatus comprises:

- ✓ An upper assembly (1); a top solid circular heavy plate (2) having sharp-edged spikes (9) provided at the bottom surface capable of piercing the defective pouches/ sachets; a middle fine knitted plate (3) capable of removing entangled pierced pouches/ sachets; a collection drum (6), provided on a base stand (8), having an upper base (4) with perforation holes (5) for placing the defective pouches/ sachets, wherein sharp-edged spikes provided at the top solid circular heavy plate (2) effectively puncture and pierce upon the defective pouches/ sachets kept on the upper base (4) of the collection drum (6); and a drain pipe (7) attached to the collection drum (6).
- ✓ the top solid circular heavy plate (2) of the apparatus is capable of pressing out the filled liquid from the pierced (cut) pouches/ sachets by effectively pressing upon such pouches and sachets kept at the upper base (4) of the collection drum (6) using a hydraulic/ pneumatic/ pulley based system attached to the upper assembly (1).

- ✓ the attached hydraulic/ pneumatic/ pulley-type mechanism is capable of retracting the top solid circular heavy plate (2) of the assembly back (up) once the piercing and pressing of the liquid-filled pouches/ sachets are complete.
- ✓ the top solid circular heavy plate (2) of the assembly is moved up and down along the verticle circular shaft mounted upon the top of the collection drum (6) being used to collect the extracted liquid and to provide firm support for smooth movement of vertically placed top solid circular heavy plate (2) within its boundaries.
- ✓ the extracted liquid can be collected in the collection drum (6) integrated into the upper base (4), which can further be connected to a primary oil tanker using valves and pipe (7). In this innovative apparatus, the top solid circular heavy plate (2) and sharp-edged spikes are made of stainless steel.

In brief, from the above details and description, it can be easily understood that the present apparatus (innovative pouch/ sachet cutter) is a safety-enriched standing-position-oriented mechanized apparatus for safe extraction of the content from the damaged or defective liquid-filled pouches/ sachets in FMCG manufacturing industries. It will ensure safety in such rework activities and enhance efficiency and productivity. It helps in squeezing the complete liquid, consisting of hair oil, out of the pierced pouch/ sachet just by piercing and pressing on its own (utilizing the spike-based plate resting on a vertical up-down movement mechanism), thus eliminating the manual need of squeezing out the liquid by pressing and thus keeps the hand clean and dry as compared to the earlier situation where hand squeezing was an essential activity.

6.2.7 Physical prototype development

As mentioned in the previous section, various aspects of human factors (anthropometric, biomechanical, usability, etc.) were considered for physical product development while fabricating various components of the intended product with actual material to ensure the intended function and usability. Further, the physical prototype of the selected concept (number 7) was developed (Figure 6.14 - 6.15). As per the concept, this innovative pouch/ sachet cutter is mechanized and can be integrated into a hydraulic/ pneumatic/ pulley-based system attached to its upper assembly for mechanization. However, for practical concerns, for trial purposes, at the Factory C shopfloor, arranging for an immediate and dedicated integrating mechanism of such sort was not possible in a short span; the semi-mechanized form of this innovative pouch/ sachet cutter was developed. An additional link-bar mechanism was attached to the basic structure of this innovative pouch/ sachet cutter that enables the verticle movement of the plate with spikes to pierce the defective pouch/ sachets placed within the container base. Providing such a link-bar mechanism enables the innovative pouch/ sachet cutter to work in the same way as it was intended for its mechanized version as per the concept. The physical prototype of the pouch/ sachet cutter developed for Factory C is shown in Figure 6.14- 6.15. The detailed drafting of this product is given in Appendix A.8 (measurements in mm).

Figure 6.14: Pouch/ sachet cutter (physical prototype) (various views). (Source: author)

The collection drum's upper base, wherein the defective pouches/ sachets can be placed, is illustrated in Figure 6.15 a. Figure 6.15 b shows the close-up view of the circular plate with spikes. Beneath this plate lies an additional plate that helps remove entangled pouches/ sachets.

a b

Figure 6.15: Pouch/ sachet cutter (physical prototype) (various parts). (Source: author)

6.2.8 Factory trials

Once the apparatus's physical prototype was ready, the field trials were carried out at Factory C to understand the product's functionality and related consequences/ insights (Figure 6.16). Ten workers were engaged for factory trials, and data regarding productivity (number of pouches cut) and other physiological/ anthro-biomechanical parameters were taken to understand the exertion levels of workers while using the developed product. Data regarding usability was also gathered. Table 6.4 summarizes testing variables (physiological and anthro-biomechanical, production, usability) (n) = 10. To determine the product's potential success, various parameters of success were considered/ adopted, including performance improvements, physical/ cognitive ease, and easy adaptability (refer to Chapter 4, Section 4.2.8.1 to 4.2.8.4) as considered for the innovative pouch/ sachet cutter developed for Factory A and B.

Table 6.4: Factory Trials - Insights (Summary)

1. Productivity:

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
Number of pouches reworked per 15 min (average of 3 trials)	520 ± 14 pouches/ 15 minutes	4130 ± 78 pouches/ 15 minutes

2. Human Factors:

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
Physical exertion level measured utilizing Heart Rate	Resting/ before the start of the work: 80 ± 10 bpm After 2 hrs of work 87 ± 10 bpm	Resting/ before the start of the work: 81 ± 5 bpm After 2 hrs of work 84 ± 12 beats/minute
The muscular effort required and, therefore, fatigue level measured utilizing handgrip strength dynamometer (Make: Jamar & Model: J00105)	Resting/ before the start of the work Right: 40.1 ± 3.2 kg Left: 39.4 ± 4.1 kg After 2 hrs of work Right: 30.1 ± 8.2 kg Left: 30.3 ± 4.3 kg	Resting/ before the start of the work Right: 40.9 ± 2.8 kg Left: 39.3 ± 7.2 kg After 2 hrs of work Right: 38.1 ± 5.5 kg Left: 37.8 ± 4.7 kg
Cognitive workload measured using NASA-TLX questionnaire (MWW)	75.23 ± 11	35.7 ± 13

3. Wrist Posture:

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
Wrist Posture	Variable (no fixed posture)	Initially neutral, but extension at the end position

4. System Usability Scale (SUS):

Variable Considered	**Existing Scenario**	**Innovative Apparatus**
SUS Score	(not conducted)	88 (Excellent)

The field trials depicted that the newly developed innovative safety-enriched pouch/ sachet cutter was more productive and easier to use. It was well-received by the workers and factory management.

Figure 6.16: Field trials at Factory C. (Source: author)

6.3. Discussion

The current product design/ development process followed in this research for factory C's innovative pouch/ sachet cutter provides several key insights describing the peculiarity, vitality, rigor, and fundamental anchoring of the concepts theoretically and in an application. These insights are discussed in detail in the coming subsections.

Insights from the field survey

The preliminary ergo-audit (Singh and Karmakar, 2022) conducted on the shopfloor of Factory C located in Assam, India, revealed that this factory employs a large number of employees as compared to Factory A and B and is more automated. Its production scale is of the order of large-scale production units (mega sector). However, the rework activity in Factory C is done manually, engaging casual labor that reworks almost 0.4 million pouches/ sachets in a day and leaves the cut pouch/ sachets overnight in collection drums if the rework activity remains pending. As the work demand of rework activity in this factory is extremely high, even the innovative cutter developed for Factory B was not suitable to cater to the work demand of the workers/ factory management of this factory. Subsequently, their specific work parameters and needs/ requirements were assessed, and the design and development of context-specific innovative pouch/ sachet cutter for them was sought.

Insights from the product design phase

The product design and development process (Ulrich and Eppinger, 2016) comprising concept generation, concept screening, virtual prototype development, physical prototype development, and field trial was deployed as done for the innovative pouch/ sachet cutter for Factories A and B (refer to Chapters 4 and 5). In this chapter, specific to the design/ development of the pouch/ sachet cutter for Factory C (the representative of the large-scale production unit working under a mega sector); as the need/ requirement varied, the concepts generated varied in terms of shape, construction, product architecture, etc. A total of ten concepts were generated using a Morphological chart (Norris, 1963; Verma and Karmakar, 2021; Singh and Karmakar, 2024) and by deploying the Pugh chart (Pugh, 1991; Lin and Hsiao, 2019; Wu and Hsiao, 2019; Singh and Karmakar, 2024), the best concept was selected, and a virtual prototype of that was developed. Further, the physical prototype of the selected concept was developed in a semi-automated form.

Careful consideration of anthropometric and biomechanical parameters has been incorporated while designing and developing the present 'pouch/ sachet cutter.' Various anthropometric parameters, like elbow height, lower position height while standing erect, forearm circumference, etc. (Chakrabarti, 1997), were considered for designing the various product features/ dimensions while developing the virtual model of the product. These anthropometric landmarks were considered for the optimal population percentile as per the needs and requirements of the intended workers of Factory C. Table 6.5 depicts a few of such anthropometric considerations used in the design phase.

Table 6.5: Anthropometric considerations used in the design phase. (Source: author)

Sr. No.	Parameter/ Feature Considered	Anthropometric Landmark Considered	Population Percentile Considered	Dimension (mm)
1.	Drum's upper edge (container's side wall height)	Elbow height + allowance (standing and erect)	50^{th} percentile combined data (male-female population)	(1020 + 30) mm = 1050 mm
2.	Drum base plate (where pouches are laid/ kept)	Lower position height + allowance (standing and erect)	50^{th} percentile combined data (male-female population)	(779 + 58) mm = 837 mm
3.	Gap between the upper edge and the spike plate	Forearm circumference + allowance (relaxed, standing)	50^{th} percentile combined data (male-female population)	(228+22) mm = 250 mm

Although this innovative apparatus has to be mechanized, a semi-mechanized form of it was developed for the present factory trials. Even for its semi-mechanized version, several biomechanical considerations were carefully thought of while designing the product to keep the wrist posture in a neutral position while using the intended product. In addition, various ergonomic principles of hand tool design were also considered. The biomechanical features considered in this design phase are as follows:

- The initial position of the moving handle for generating compressive force was kept below the shoulder level to avoid extreme upper arm flexion. The entire movement range of the handle was decided in such a way as to prevent the extension of the upper arm and be within the comfortable range of movement of the elbow flexion.
- The distance between the two holding handle grips was decided to avoid abduction of the arm.
- The arrangement of the handle and its range of movement was decided in such a way that the operator could exert the required compressive force for piercing the defective pouches/sachets.
- The apparatus was mounted along with a wooden platform on which the operator could stand and operate to avoid slippery floors. Moreover, this arrangement would also prevent the apparatus from toppling during its operation.

- Ergonomic principles of hand tool design were considered during the concept development, viz., handgrip strength, grip diameter, wrist posture, handbreadth, etc. Rubberized material for the handle was used/ given to reduce contact pressure between the palm and handle surface.

This adopted method of selecting anthropometric and biomechanical parameters for product development is in corroboration with other innovative product development studies (Sanjog and Karmakar, 2019; Verma and Karmakar, 2021; Singh and Karmakar, 2024).

The fully functional innovative product, a safety-enriched pouch/ sachet cutter, was developed using thoroughly explored design and ergonomics principles. It was further taken for field trials at Factory C to assess its functionality, performance, and user acceptance. The following subsection discusses the key insights gathered from the factory trials.

Factory trial phase

Post-development of the physical prototype of the safety-enriched cutter, the field trials at Factory C were conducted to evaluate several essential parameters deemed fit for its performance analysis and user acceptance level assessment. Table 6.4 summarizes the observations/ results of these specific parameters for the existing and improved scenarios (using a newly developed safety cutter). This comparison provides vital information and insights about the products's level of success and other relevant concerns.

The number of pouches reworked using the existing method and with improved cutter were taken into account to determine the productivity levels. Trials for 15 minutes were recorded for each worker, and three such trials were taken. The average of three trials was used for reporting purposes. It revealed that the existing method, wherein the pouch/ sachet cutting was done using a sharp cutter/ blade held in bare, slippery hands, and hand squeezing was carried out, and the workers were able to cut on average 520 ± 14 pouches. However, with the use of a newly developed safety cutter capable of cutting and squeezing multiple pouches/ sachets at a time, the average number of pouches/ sachets reworked rose to 4130 ± 78 per 15 minutes. This was attributed to the capability of the present innovative cutter to rework multiple pouches/ sachets at a time, as there was no need for systematically arranging the pouch/ sachets before putting/ placing the pouch/ sachets in the upper base of the collection drum. An ample number of pouches/ sachets (300-400) can be loaded randomly on the upper base of the collection drum. Once the pouch/ sachets are loaded, with a single stroke of the downward moving plate with spikes, those are pierced, and liquid content gets squeezed to be collected in the integrated container through perforated holes. It was a significant improvement in the context of productivity levels and efficiency. It can be attributed to the fact that while using the newly developed cutter, the workers were not compelled to use sharp blades/ cutters or manual hand-squeezing. The newly developed innovative pouch/ sachet cutter helps in squeezing the complete liquid, consisting of hair oil, out of the pierced pouch/ sachet just by piercing and pressing on its own (utilizing the spike-based plate resting on a vertical up-down movement mechanism); thus eliminating the manual need of squeezing out the liquid by pressing and thus keeps the hand clean and dry as compared to the earlier situation where hand squeezing was an essential activity.

For an assessment of the product's compatibility with the job/ activity, tool-worker interface, and related consequences, the human factor evaluation based on physical exertion level using heart rate, fatigue level measurement using handgrip strength, and cognitive load assessment using NASA-TLX was performed for the existing and improved scenarios was conducted.

Physical exertion level was measured utilizing the Heart Rate. Heart Rate was taken for each worker in the resting state, i.e., before the start of the work and after 2 hours of work. For the existing scenario, the Heart Rate before the start of work was 80 ± 10 beats/ minute (bpm) and was 87 ± 10 bpm after 2 hours of work. While using the newly operated pouch/ sachet cutter, values were 81 ± 5 bpm and 84 ± 12 bpm, respectively. From these values, it is evident that there is no major deviation in physical exertion levels while operating with the newly developed cutter. The exertion levels in both scenarios are almost in line with each other; rather, in the improved scenario, the Heart Rate values were lower at the end of the 2 hours of work. It can be concluded from the facts that the newly developed cutter is easy to operate and handle and does not exert much physical exertion on the workers, as ascertained from the Heart Rate values recorded.

The handgrip strength values measured the muscular effort required to perform the rework job/ activity and the induced fatigue. In existing scenarios, the recorded values for the resting/ before the start of the work were 40.1 ± 3.2 kg and 39.4 ± 4.1 kg for the right and left hand. The obtained values for the handgrip strength after the 2 hours of work were 30.1 ± 8.2 kg for the right hand and 30.3 ± 4.3 kg for the left hand. For the improved scenario, wherein the need for manual hand squeezing was eliminated, the obtained values were 40.9 ± 2.8 kg for the right hand and 39.3 ± 7.2 kg for the left hand at the resting state (before the start of the work).

At the end of 2 hours of work, the obtained values were 38.1 ± 5.5 kg and 37.8 ± 4.7 kg for right and left hand, respectively. These values show that the decrease in handgrip strength is lower in the improved scenario than in the existing scenario. It can be interpreted that the use of a newly developed cutter capable of auto-squeezing (by virtue of its heavy piercing cum pressing plate) helps minimize the fatigue induced by manual hand squeezing. A lot of workers' effort to manually squeeze liquid from cut pouches/ sachets is saved using the newly developed cutter. Moreover, it eliminates the chances of contamination that may occur due to liquid contents touching hands. Thus, this newly developed cutter reduces drudgery.

Cognitive Load Measurements were done by administering the NASA-TLX questionnaire and calculating the overall MWW. The obtained MWW value for the existing scenario was 75.23 ± 11, an indicator of the high cognitive workload associated with the rework activity being carried out in the existing scenario wherein the sharp cutter/ blade is held in bare, slippery hands, and manual hand squeezing was required. In such a scenario, workers must remain cautious, work slowly, and exert high manual effort (for squeezing) to perform their rework task without any standardized/ context-specific tool/ apparatus. These factors account for the higher cognitive workload as indicated by the obtained overall MWW values. However, as a newly developed safety cutter eliminates the need to hold the cutter/ blade directly in the hand and subsequent hand-squeezing, the cognitive load decreases, as indicated by the obtained MWW value, which is 35.7 ± 13. Hence, it is evident that the present innovative ergonomic design intervention is capable of reducing the perceived physical and cognitive demand and effort among the workers engaged in rework activity.

Biomechanical posture compatibility evaluation for the newly developed cutter was assessed by minutely observing the 'Wrist' posture while performing the rework activity in an improved scenario. The wrist was mainly used to hold the handle and move the spike plate downwards within the upper base of the present innovative pouch/ sachet cutter. So, for compatibility of the highest concern, keen observation of the probable use of the wrist while performing the job/ activity was considered. The 'Wrist' remained in a 'Neutral' position at the initial position, but extension was observed at the end position. It was also observed that:

- There was no upper arm flexion at the initial position, as the initial position of the moving handle was below shoulder height.
- The entire movement range of the handle during the operation was within the comfortable range of movement of the elbow flexion.

These observations confirmed the biomechanical posture compatibility of the newly developed cutter for this rework activity. It assures that the newly developed cutter can be used with ease, will not cause any harm while being used, and is perfectly adaptable to the needs of the rework activity. No such evaluation was possible in the existing scenario as no standard way of working exists. Workers tend to work in variable postures, particularly involving the wrist. The newly developed cutter provides a standard context-specific tool for rework activity and a standard way of working using the same. It is a major shift from a non-standardized activity towards standardization achieved via a context-specific innovative tool/ apparatus design and development approach.

User acceptance (usability evaluation) of the newly developed cutter was measured by administering the SUS questionnaire. A SUS score of 88 was obtained, depicting an 'Excellent' and 'Acceptable' usability rating, according to the adjectives shown in Table 6.6. The respondents rated for the 'positively phrased' and 'negatively phrased' questions while responding to the requirements of the SUS questionnaire. It was observed that, for odd-numbered questions (positively phrased), the responses were mostly 'agree' and 'strongly agree'; in contrast to even-numbered questions (negatively phrased), high response percentages were mostly between 'disagree' and 'strongly disagree.' As a result, an overall SUS score of 88 was obtained. It reflects the wide acceptability of the newly developed tool/ apparatus among the intended users and its success. They expressed their readiness to adapt to the newly developed innovative tool. No such evaluation was done in the existing scenario, as no new tool/ apparatus existed for assessment.

Table 6.6: SUS score and associated rating and interpretation. (Source. Brooke, 1996)

SUS Score	Adjective Rating	Acceptability
89-100	Best Imaginable	Acceptable
84-88	Excellent	
71-83	Good/ Very Good	
50-70	OK	Marginal
32-49	Poor	Unacceptable
20-31	Awful	
0-19	Worst Imaginable	

6.4 Developmental Cost

The physical prototype of the newly developed safety-enriched pouch/ sachet cutter was developed for factory trials. The representative cost for fabricating a single piece of such a prototype is depicted in Table 6.7.

Table 6.7: Representative cost for fabricating a single piece (prototype). (Source: author)

Cost Head/ Description	Cost (in USD)
Raw material	190
Fabrication charges	300
Miscellaneous charges	65
Total cost for one prototype	555 (an additional cost of 1200 USD might be required for adding a pneumatic/ hydraulic system for automation)

This cost is for fabricating a single prototype for factory trial. It is expected that the price of the final product (commercially available product) will be reduced to a great extent when mass manufacturing of such products is done.

6.5 Conclusion

Chapter 6 describes in detail the systematic user-centered product design approach followed for the design and development of a safety-enriched pouch/ sachet cutter for Factory C (representative of large-scale production units), more particularly for the context-specific need/ requirements of Factory C governed by its scale of production and work parameters. Following the current research, an innovative pouch/ sachet cutter was developed, considering ergonomic and design principles. It is capable of ensuring safety in rework activity as it eliminates the need to hold a sharp cutter/ blade in bare, slippery hands. Moreover, it reduces drudgery as it eliminates the need for manual hand squeezing and perhaps helps minimize the source of contamination. This innovative tool/ apparatus, which was designed with various anthropometric and biomechanical considerations in the development phase, was well received by factory workers and management. It fulfills their specific needs associated with their work style adopted in regard to rework activity and, in conjunction, fulfills the aim of this current research at Factory C that recites 'To design and develop a safety-enriched pouch/ sachet cutter for rework activity performed in a factory with large scale production level. Such a pouch/

sachet cutter must be capable enough to cut 250-500 pouches/ sachets at a time and eliminate the need to hold a sharp cutter/ blade in bare, slippery hands and hand squeezing'.

Additionally, as the product is innovative and has market potential, protecting the Intellectual Property Rights (IPR) of this tool/ apparatus was deemed necessary. For this purpose, the utility patent and design registration were secured for the present innovative pouch/ sachet cutter. Researchers have protected its IPR well in its parent country (India). As this research relates to innovative product design and development, the IPR was a major stake, and those were secured first, and reporting to journal publication is under process.

6.4.1 Scholarly outputs

Efforts were made to derive various scholarly outputs from this practical research conducted at Factory C. Table 6.8 below summarizes the scholarly outputs achieved from this work.

Table 6.8.: Scholarly outputs from present work. (Summary)

Component	**Details**	**Status**
Utility Patent (India)	Patent No.: IN 364959	GRANTED and In Force
Design Registration (India)	Design No.: 329288-001	GRANTED and In Force

7

Discussion and Conclusion

Abstract

This Chapter discusses and analyzes the study's general findings in light of the current investigation's goals, objectives, and research questions. Also included are the goals being met, the hypothesis being tested, novelties, contributions, limitations, future scope, and the conclusion.

7.0 General Discussion and Framework Developed

The current research relates to the improvement activities of the industrial shopfloor, particularly on the Indian Fast Moving Consumer Goods (FMCG) shopfloor. It attempts to look deeply into industrial shopfloor activities and their associated ergonomics, production, and safety-related issues and then prioritize the areas of concern that must be addressed in the current instance. Once the area of critical concern was selected, it took up the challenge of providing a mitigating solution to address the safety-related issues that prevailed on the shopfloor of Indian FMCG units. The proposed mitigating solutions in the current research are based on the thorough implementation of ergonomics and design principles. Several insights were gathered while conducting this research study in several phases, which are discussed in the following sub-sections.

Initial literature review and research gap identification

The literature on the 'use and implementation of ergonomics in the industrial sector' was explored to learn about state-of-the-art ergonomics and its scope in the FMCG domain. The literature review revealed that ergonomics was implemented in a scattered form in various industrial sectors to assess OSH conditions. Its penetration remains shallow within the industrial sector, and most of the research conducted in this domain remains at the level of MSD evaluation (Singh and Karmakar, 2021, 2022, 2023). Such research has indicated the prevalence of various OSH and safety-related issues that prevail on the industrial shopfloor (Feuerstein et al., 2004; Marras and Karwowski, 2006a,b; Werner et al., 2010; Commissaris et al., 2016; Bridger, 2017). Although the researchers have advocated the benefits of implementing ergonomics in industrial work, it has failed to lure the industrial stakeholders, and the awareness of it remains low, especially in the IDCs (Shahnawaz, 2009; Sanjog et al., 2016; Singh and Karmakar,). There lies a dire need to create awareness about ergonomic principles and their benefits in industrial work by implementing and taking up research studies in this domain.

In the context of FMCG research, it was found that the research being conducted in this domain remains focused on the managerial and production aspects, i.e., on achieving production/ operation excellence (Singh and Karmakar, 2021, 2022). Most industrial stakeholders remain busy steering their day-to-day routine and rarely focus on ergonomics and OSH-related research to improve their OSH conditions and productivity. There lies a wide gap between the academia-industry relationships in the context of ergonomics and its awareness.

This wide gap, as indicated by the literature review, was helpful to the researcher in realizing the importance and immediate need for conducting full-fledged research in the FMCG manufacturing sector from an ergonomics perspective.

Preliminary field study in Indian FMCG manufacturing units

In the current research, post-gap identification, in-depth preliminary research was conducted on twenty FMCG manufacturing units operating in Assam, located in the northeastern region of India. It aimed to identify the various ergonomic and OSH-related issues that prevail on FMCG shopfloor and are prone to risk and hinder productivity. Several ergonomics and OSH-related issues were identified that can be broadly categorized into three broad categories: ergonomic stressors, non-standardized work activities, and unsafe work activities. Anthropometric mismatch, long working hours, inadequate tools/ apparatus, non-standardized work activities, environmental hazards, unsafe work activities, etc., were common OSH-related issues that prevailed on the shopfloor (Singh and Karmakar, 2022). Rework of defective pouches/ sachets was found to be the most critical unsafe activity, as it was prone to cuts/ injuries and required immediate attention from the workers and factory management's purview. Mitigating solution for this unsafe activity of prime concern was taken up. It was observed that FMCG manufacturing units were working under different production scale levels, and this rework activity prevailed on all shopfloors. However, their work demands differ, and it was assumed that a single design intervention might not be a perfect solution to cater to the needs of all three levels of production scale, viz. low, medium, and large production scale. So, step-by-step research was conducted to design and develop an innovative design solution for each level of the production scale represented by Factory A, Factory B, and Factory C, respectively. The design and development of innovative solutions were thoroughly based on the implementation of design and ergonomic principles.

Design/ development and field trial phase

The current research used the Morphological chart to develop multiple context-specific concepts for Factory A, B, and C based on their distinct needs/ requirements. The same Morphological chart was used to develop varied concepts for each factory under consideration because the same set of morphological components (component-specific design solutions) addresses the functional/ sub-functional requirements of the intended product/ apparatus. The primary function/ sub-functions, viz. cutting, squeezing, and collection, were common for all varying levels of product/ apparatus; however, the level of complexity of those varied.

Further, the different concept spaces were developed by addressing the context-specific needs/ requirements of the specific levels of industries (low, mid, and high levels). The selection of morphological component/ design component against each function/ sub-function significantly varied according to the needs/ requirements of different levels of production scale of the industry. Thus, the amalgamation of selected design components for function/ sub-functions resulted in completely different concepts in each of the three cases.

A Pugh chart was used for concept screening. The different Pugh charts were used for each case (Factory A, B, and C). Apart from the difference in weightage in basic selection criteria in the Pugh chart, the number of selection criteria also varied as per the needs/ requirements at each level of varying production scales. For example, Table 4.3 has eight selection criteria and associated weights. In contrast, Table 5.3 has ten, and Table 6.3 has eleven selection criteria and related weights as per the context-specific needs/ requirements of work demand. The varying selection criteria according to the varying levels of production scale helped conceptualize the varying levels of product complexity, viz. simple, mid-level, and marginally complex.

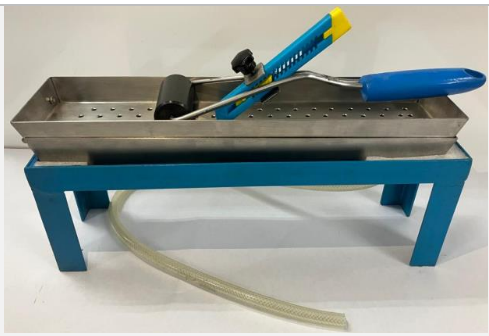
The hand-held innovative tool was initially developed for Factory A, representing low-production scale manufacturing units. A rigorous field trial was conducted to test the feasibility and effectiveness of the innovative solution that was devised. It was found suitable for the needs of Factory A. However, upon approaching Factory B with the product devised and field trial data, it was found that this tool/ apparatus would not be sufficient to cater to their needs. Thus, their context-specific needs were taken into consideration, and another hand-held apparatus was devised for Factory B. Field trials were conducted for it on the Factory B shopfloor. The workers in the Factory B well received it. However, Factory C, a representative of a high-level production scale, does not hold the same opinion for the innovative product developed and its related field trial data. They conveyed that their needs differ, and using this tool at their workplace may not be possible. Thus, their needs were noted, and a new innovative product was developed for Factory C. Rigorous field trials were done for it at Factory C. It was well-received by the stakeholders at Factory C.

From this entire exercise, it was found that a context-specific innovative solution devised according to the needs and requirements of each level of the factory was an optimal solution. However, the same systematic design strategy based on ergonomic and design principles could devise an optimal solution for each level of production scale. The tools/ apparatus devised were found to be useful, commercially viable, affordable, and suitable for the needs of each manufacturing unit. Those were capable of enhancing safety within the rework activity, as they eliminated the need to hold the sharp cutter/ blade in bare, slippery hands and the need for manual squeezing. It was observed that the rigorous design and development philosophy used in this entire process was a very meticulous design strategy that can be replicated/ imitated by other researchers to devise other innovative solutions for other unsafe job activities in other diverse industrial sectors and thus paved the way for documentation of the potential actionable design strategy and guidelines. Therefore, a framework was chalked out that may be used by other researchers as a ready reckoner.

Future plans for the commercialization of developed innovative products

The present practical research (based on the implementation of design and ergonomic principles) led to the successful design and development of three different levels of innovative products. These were developed to cater to the context-specific needs of rework activity being performed at the FMCG manufacturing units working under varied scales of production (refer to Chapters 4,5 and 6). Table 7.1 summarizes the details of these innovative products:

Table 7.1:. Innovative products developed (Summary). (Source: author)

Product	Patent Number / Design Number	Product Image	Tentative Cost (in USD)
A	**US** 11319103 **IN** 355304 **IN** 329290-001		270
B	**IN** 415999 **IN** 360578-001 **AU** 2022238038 **US** 18020030* **Under examination*		475

C	**IN** 364959 **IN** 329288-001		555 (an additional cost of 1200 USD might be required for adding a pneumatic/ hydraulic system for automation)

Intellectual Property Rights (IPR) of all these products were secured in the parent country and other countries like the United States of America and Australia. Utility patents and design registrations for these products have already been granted in India. The rework activity is prevalent across the FMCG manufacturing units among the developing nations. Thus, these innovative products have high commercial potential and worth. Considering the vast potential of these products, the following plans for their commercialization may further be explored:

- technology transfer to the interested Original Equipment Manufactures (OEM)
- technology transfer to the interested individual entrepreneurs
- technology transfer to the statutory bodies governing the safety-related issues in designated countries (e.g., DGFASLI in India and many others)

For future commercialization, the patentee and interested parties can have formal dialogue/ interaction and agreements to move further with reaping the benefits of the developed technology.

Framework for developing safety-related design interventions for the factory shopfloor

In the current research, the researcher deployed a rigorous design and development process based on the thorough implementation of ergonomics and design principles to develop an efficient mitigating solution to improve the prevailing adverse working conditions on FMCG shopfloor with varying scales of production levels and associated parameters. It encompasses minute details from the inception stage (pre-conceptual phase) to the field trial (success determination phase). These steps provide an actionable strategy/ guideline to help other researchers carry on such efforts/ attempts in various industrial sectors. They may adopt and use this framework as a ready reckoner.

Phase I of the framework primarily elaborates upon the stages/ steps to be followed for an effective need identification. It encompasses various stages, viz. preliminary ergo-audit, prioritization of critical areas of concern, and approaching the context-specific design intervention. Phase II deals with the stages of development of design intervention (product/ tool/ apparatus design). It covers the systematic design strategy comprising design limits selection, concept generation, concept screening, mock-up development, prototype design, and subsequent field trials.

This framework is generic in the context of addressing the OSH issues through design interventions in the industrial/ manufacturing units working under manual and semi-automated setups but not for fully automated ones. It is beneficial for the industrial sectors where varied production scale levels exist for similar products. It describes the detailed methodology for identifying ergonomic stressors and safety-related issues in any industrial sector, particularly when working in manual and semi-automated production setups with injury-prone scenarios. The framework derived from the current research seems to be generic and common from the perspective of providing ergonomic design intervention to address OSH issues on any industrial shopfloor, but it is unique in terms of its capability to cater to the specific needs/ requirements of varied level of production scale (as indicated in Phase III of the framework). The framework is beneficial for the industrial sectors where varied production scale levels exist for similar products.

The current research's design and development strategy can be adopted by other researchers for various industrial domains. For quick reference/ adoption by other researchers, such a strategy is presented as the framework (Fig. 7.1).

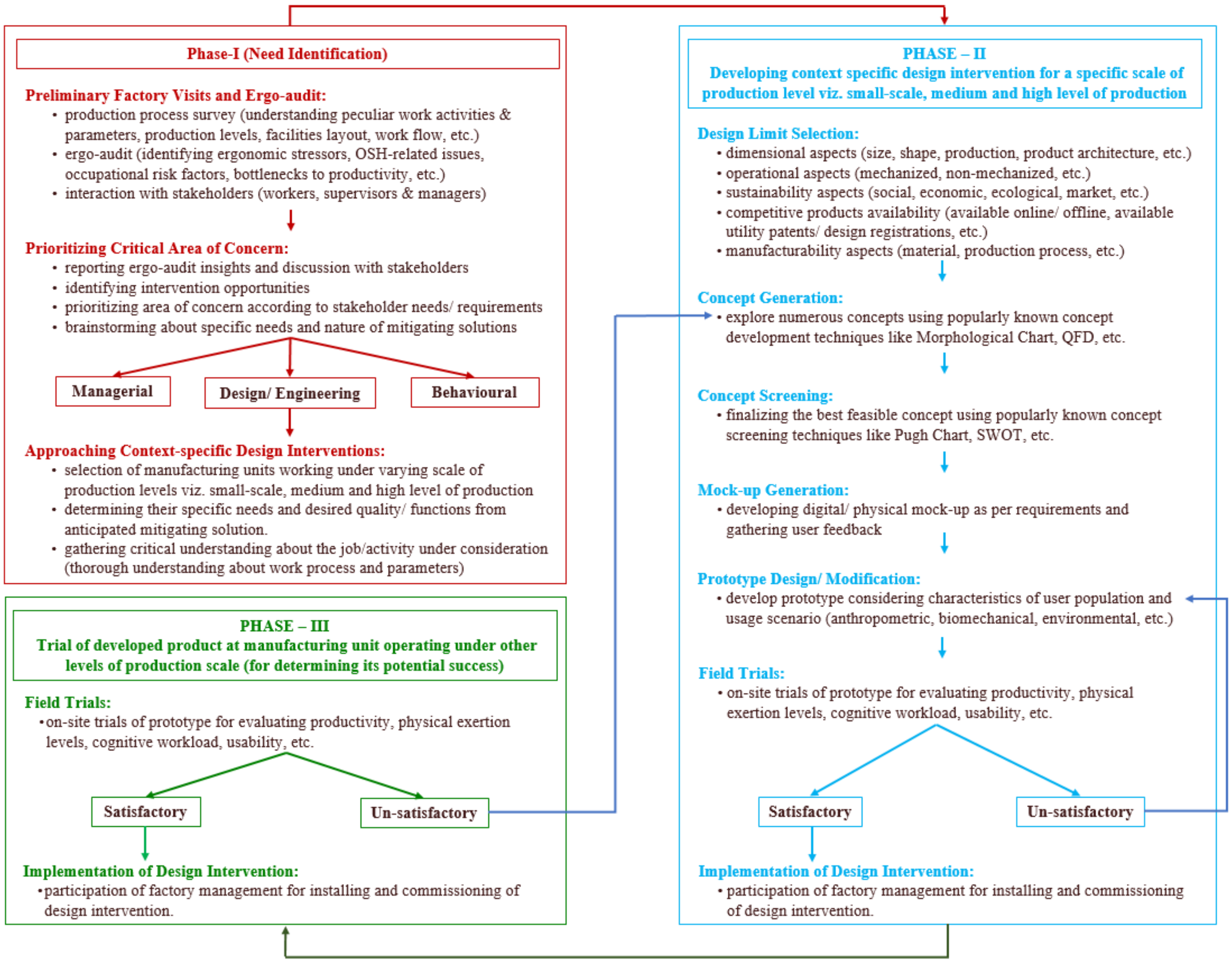


Figure 7.1: Framework for developing safety-related design interventions for the factory shop floor. (Source: author)

7.1. Salient Findings

The following are salient findings of the present research regarding the improvement of shopfloor working conditions in Indian FMCG manufacturing units from an ergonomics perspective:

- Ergonomics – the science of man-machine compatibility has been scantly explored within the industrial domain, especially within the IDCs. Only scanty research related to ergonomics and OSH considerations exists in an industrial concern.
- The majority of the research conducted in the industrial arena from an ergonomics perspective focuses on diagnosing the prevalence of MSDs and other ergonomic stressors on the shopfloor. It does not provide mitigating solutions for the same, especially in an innovative product form.
- The research within the FMCG sector from an ergonomics perspective is almost negligible. The research in this sector is primarily focused on production/ operation excellence-related work aspects, especially the management-related attributes.
- Plenty of ergonomic stressors, OSH issues, and safety-related issues prevail on the FMCG shopfloor and remain a great concern for shopfloor workers and factory management.
- The FMCG manufacturing units work at varied production scale levels. Yet, many non-standard unsafe work activities prevail on their shopfloor, and their intensity/ impact varies according to the production/ operation scale.
- Context-specific innovative design solutions according to the varying needs and requirements are essential to devise mitigating solutions for the existing unsafe activities.
- Thorough implementation of ergonomic and design principles is instrumental in developing practical, innovative design solutions for improving the safety and well-being of those involved in unsafe activities on the FMCG shopfloors.
- The design strategy to design and develop the innovative tool/ apparatus for the context-specific safety-related issues and challenges is easily replicable. Researchers may further use it to devise similar solutions in diverse industrial sectors.
- Securing Intellectual Property Rights (IPR) for the innovative product developed may prove beneficial while moving forward for further commercialization aspects.

7.2 Addressing Research Gaps and Fulfillment of Objectives

Objective 1: To understand the state-of-the-art literature on ergonomic issues and the implementation of ergonomic interventions in diverse industrial sectors.

Foremost, attempts were made to understand the state-of-the-art literature pertaining to ergonomic issues and the implementation of ergonomic interventions in diverse industrial sectors, which were studied from the existing literature and compiled in Chapter 2. The current research trends associated with FMCG manufacturing were also explored. The scope of interventions in FMCG manufacturing was explored along with the probable tools and techniques that are important concerning FMCG work parameters. These have been discussed in Chapter 2.

Objective 2: To study the OSH-related issues in the Indian FMCG shopfloor.

A rigorous preliminary ergo-audit was conducted in twenty FMCG manufacturing units located in northeast India. Several issues concerning the OSH scenario were identified based on the ergo-audit conducted. Those were categorized and compiled to discuss with the various stakeholders (workers, production managers, safety managers, factory management, etc.) to identify the most critical areas of concern that must be prioritized to provide a mitigating solution. The first half of Chapter 3 relates to this objective.

Objective 3: To identify the most critical areas of concern in the context of work/ worker safety.

The most critical area of concern was identified by card-sorting sessions, discussions, and interviews with the various stakeholders. The rework of the pouch/ sachet was identified as the most critical area of concern as this job/ work activity was prone to cuts, injuries, and accidents due to the non-availability of standardized tools for this non-standardized activity. No standardized tools exist for this prominent activity, thus becoming a safety challenge for workers engaged and factory management. It was agreed to devise innovative mitigating solutions for this activity, and it was observed that a single solution may not be a perfect fit for varying levels of FMCG work and associated work parameters. Different context-specific tools per the work parameters of the varying levels of manufacturing units' needs were deemed necessary. Three different manufacturing units working under varied scales of production were chosen for further research and subsequent innovative product design and development purposes. The latter half of Chapter 3 discusses these issues in detail.

Objective 4: To design and develop innovative context-specific ergonomic design interventions as a mitigating solution.

Three different context-specific tools were devised per the manufacturing units' distinct needs. An innovative pouch/ sachet cutter was designed and developed by implementing thorough ergonomics and design principles from its pre-conceptual to the field trial phase. In the current research, three innovative safety-enriched tools were developed for the FMCG manufacturing units (Factory A, B, and C, representative of small-scale, medium-scale, and large-scale production levels), and Chapters 4, 5, and 6 discuss all the stages of innovative product design and development in detail.

Objective 5: To evaluate the efficacy of the developed innovative design interventions.

Once the three context-specific innovative pouch/ sachet cutters were developed, a rigorous field trial of those was carried out on the concerned factory shopfloor to evaluate the efficacy of the devised tools. Various parameters of success were considered/ adopted to determine the product's potential success, including performance improvements, physical/ cognitive ease, and easy adaptability. Various parameters, viz., number of pouches cut, physical exertion levels induced, cognitive level requirement, and usability satisfaction levels, were considered for existing and improved scenarios at each factory shopfloor (Factory A, B, and C) using the context-specific tool developed for their particular need. The latter half of Chapters 4, 5, and 6 deals with the field trial phase conducted to determine the efficacy of the developed innovative mitigating solutions.

Objective 6: To propose a framework for developing safety-related design interventions for the factory shopfloor.

In the current research, the research deployed a systematic design and development process based on the thorough implementation of ergonomics and design principles to come up with an efficient mitigating solution to improve the prevailing adverse working conditions on FMCG shopfloor with varying scales of production levels and associated parameters. It encompasses minute details from the inception stage (pre-conceptual phase) to the field trial (success determination phase). These steps provide a well-adaptable strategy/ guideline that may help other researchers carry on such efforts/ attempts in different industrial sectors. They may adopt and use this framework as a ready reckoner. It has been discussed in Chapter 7.

7.3 Testing of Hypothesis

Hypothesis 1: *The design and development of innovative tools/ devices in the context of OSH on the shopfloor of the FMCGs is constrained by the scale of production, cost, and available resources.*

Early at the preliminary ergo-audit of the FMCG manufacturing units, it was observed that the rework of pouches/ sachets is a prominent task/ job activity that exists upon every shopfloor engaged in manufacturing of FMCG goods, more particularly hair oil, shampoo, serum, etc. irrespective of the scale of production, number of workers employed, machinery involved, production strategies, etc. The researcher, at that very instance, predicted that if one is supposed to provide a mitigating solution in the form of an innovative design intervention, it can be very much apprehended that such a solution will be governed by the context-specific requirements of the production unit and their work parameters viz. scale of production, cost they want to incur on a solution, work requirements, etc. However, to put it in the trial and determination phase, three varying levels of the mitigating solution (an innovative safety-enriched pouch/ sachet cutter) were developed. Those were step-by-step validated for their potential success at Factories A, B, and C, respectively.

At first, the innovative solution for Factory A (small-scale production level) was developed and was successfully tested and validated on the shopfloor of Factory A. It was well-received by Factory A's workers and factory management as it successfully met their requirements. Then Factory B (medium-scale production level) was approached with the innovative product developed and its trial data results. Upon discussion with various stakeholders, it was found that this tool/ apparatus will not be able to cater to their needs as their work demands and parameters differ from the capabilities/ limits of the presently designed and developed safety cutter for Factory A. Further, the researcher gathered the specific requirements for their working conditions and moved on to designing and developing an innovative pouch/ sachet cutter for Factory B.

Once a new innovative safety-enriched pouch/ sachet cutter designed and developed for Factory B's context-specific needs was ready, it was put on trial on Factory B's shopfloor, where it was received wholeheartedly and validated for its success. However, as done earlier, the researcher approached Factory C (large-scale production level unit) with the developed product and its associated field trial data and discussed its probability of adoption on their shopfloor with the stakeholders. It was observed that the stakeholders were not very satisfied with the capabilities of the present pouch/sachet cutter developed, and the majority of them thought that it would not be capable of meeting their requirements and asked for a context-specific pouch/ sachet cutter as per their specific work demands. The researcher noted their requirements and moved on further to design an innovative solution for Factory C.

Post-development of the improvised pouch/ sachet cutter built according to the needs and requirements of Factory C, the pouch/ sachet cutter was put on to rigorous field trials at Factory C. The stakeholders very much appreciated it and provided feedback to ascertain its success in improving the existing adverse conditions on their shopfloor. Ultimately, the researcher realized that this pouch/ sachet cutter designed and developed as per their work requirements successfully met their needs and requirements. In contrast, the previous two versions of the pouch/ sachet cutter (for Factory A and B) failed to satisfy Factory C's stakeholders.

Upon implementation and having done rigorous field trials at each factory shopfloor, the success of each innovative pouch/ sachet cutter was assessed, and its adaptability to other factory shopfloors having varying scale production was determined. It is evident from the discussion above that each smaller version of the pouch/ sachet cutter became incapable of meeting the requirements of the factories with the larger scale of production level, and they posed the demand for higher variants of similar sort of mitigating solution and provided their distinct need and requirements for designing and developing the same. Ultimately, by this, the researcher ascertained that the design and development of innovative tools/ devices in the context of OSH on the floor of the FMCGs is constrained by the scale of production, cost, and available resources, as it was guessed earlier in the initial stage of this research.

A few observations that were gathered from testing of the hypothesis are summarized below:

- A hand-held pouch/ sachet cutter capable of cutting 5-10 pouches/ sachets at a time is perfectly suitable for Factory A and its work requirements. It is a low-cost, innovative solution designed and developed for cutting smaller numbers of pouches and sachets and is simple in construction. It can be made in-house using simple construction material (it involves simple mechanisms that can be replicated/ imitated) or directly procured from the market at a cheaper cost.

- Factory B was satisfied with the mid-level hand-held pouch/ sachet cutter, which was hand-held and based on three assemblies: cutting, roller squeezing, and containing assembly. It can cut multiple pouch/ sachet strips at a time and thus rework large numbers of pouches/ sachets, probably 25-100 pouches/ sachets at a time. It is of mid-level complexity, involves several integrated mechanisms/ assemblies, and requires higher costs to procure.
- A semi-mechanized variant of the pouch/ sachet cutter was found suitable for the needs and requirements of Factory C as it was involved in the reworking of the higher number of pouches/ sachets at a time of the order of 250-500 pouches at a time. Mechanization of this innovative pouch/ sachet cutter is possible (through the provisions to integrate with pully/ hydraulic system, etc.), and it may be installed at some dedicated space on the shopfloor. Such mechanized operating requires a dedicated motor, pulley, and hydraulic/ pneumatic system. It is complex in construction and requires several other accessories/ peripherals for its efficient operation, so it needs high capital requirements for its initial setup and subsequent working.

7.4 Novelties of the Study

The novelties attributed to the present research are discussed below:

- The literature indicates that the research carried out so far in the industrial sector from an ergonomics perspective remains limited to diagnostic studies, thereby proposing recommendations from the OSH perspective that include available standard guidelines (preventive measures, physical exercise, and therapy, rehabilitation measures, etc.) that may work for the betterment of occupational health. However, the current research is the first-of-its-kind research in a developing country's industrial sector that is not only a descriptive OSH-related study but also a prescriptive study with guidelines and real/ practical implementation of safety-enriched innovative products as mitigating solutions.
- The tools/ apparatuses developed to ensure safety for the selected unsafe activity, i.e., pouch/ sachet rework, have been developed considering three different scales of production level and associated attributes. This approach for product design and development of the tool/ apparatus addresses the same concern but for three different levels of production scale, which is unique, as reported in the current research.

- So far, the reported research has mainly been concerned with the standardized work activities and practices of the industrial shopfloor and has drawn maximum attention from the researchers. The current research picked up non-standardized work activity that is prone to injuries/ accidents and needs immediate attention. It also developed context-specific tools/ apparatuses to address unsafe work practices. This is probably a first-time approach for looking at and taking appropriate measures for unnoticed activities on the formal sector's industrial shopfloor.
- The current research is a good example, wherein the designed and developed products have been protected for their Intellectual Property Rights (IPR) and implemented on an industrial shopfloor. All three innovative tools/ apparatuses have been protected from the IPR perspective both in terms of their design and utility.

7.5 Contributions of the Study

A summary of all the key contributions imparted by the current research is summarized below:

Contribution to the knowledge base

The original and generic pieces of knowledge that are evolving from the current thesis is that the design intervention in any industrial shopfloor context is also constrained by the scale of production, cost, and available resources, apart from all other routine and well-known design limits selections (dimensional aspects, operational aspects, sustainability aspects, manufacturability aspects, etc.) adopted by designer/ researcher in their pre-conceptual stage of design process.

In addition, as there lies a paucity of research about FMCG manufacturing from an ergonomics aspect, the current study has enriched the knowledge base with new insights, compilation, and mapping of existing ergonomic tools/ techniques with the FMCG work activities that may further help the researchers, shopfloor engineers, safety personal, factory administrators to devise strategies to have a quick look and quick analysis of the OSH scenario on their shopfloor. As already discussed, most research related to OSH concerns within the industrial sectors is limited to diagnosing and assessing the prevalence of MSDs and reporting other ailments. The entire approach deployed in the current research towards providing a mitigating solution to the FMCG's critical activity is a piece of new knowledge to the FMCG literature. It paves the way for other research activities to look into other vital activities of prime concern in FMCG manufacturing.

Contribution to methodological perspective

As discussed above, this research demonstrates the application of the systematic design research methodology well to develop innovative design interventions for critical FMCG work activity with varying levels of production scale and associated attributes. It is a rigorous methodology that has been meticulously presented within a single thesis. It can be implemented/ replicated by other researchers, shopfloor engineers, and those interested in similar industrial work improvements.

Concerning the research's generalizability, the present thesis describes the generic methodology for identifying ergonomic stressors and safety-related issues in any industrial sector. The ergo-audit and, thereby, application of different ergonomic evaluation techniques described in the thesis can be adopted by any researcher/ designer/ engineer while they are in the process of identifying ergonomic stressors on the shopfloor of any similar or related industrial setups. The techniques for prioritization of the identified critical areas of concern in the FMCG shopfloor, as followed in the current research, can be adopted by the researchers in prioritizing/ identifying the most critical issues that need to be addressed in the design research, which will have a cascading effect on other related problems.

This systematic design philosophy, well executed and demonstrated in a nutshell, may further motivate young researchers to take up such studies on factory shopfloors that are generally considered strict formal environments requiring years of expertise before setting foot in there. A successful demonstration of the design and ergonomic principles to provide an innovative design intervention for the industrial problem may boost the confidence of the industrial personnel and make them more aware of the benefits of applying ergonomics on their shopfloor and help them to get more associated with the researchers from the academia to conduct such studies on their shopfloor. Bridging the gap and minimizing the industrial personnel's trust deficit in the academician's capabilities is the major contribution of the methodology adopted within the present research.

Contribution to the industrial sector

The methodology adopted within the current research generates awareness of ergonomics among various stakeholders in the FMCG domain. The ergonomic principles applied along with the systematic design strategy have been instrumental in providing mitigating solutions for varying levels of critical FMCG problems. As a deliverable, the present study provided three different innovative pouch/ sachet cutters that are well-suited to the specific requirements of the FMCG manufacturing units. They may adopt and use these safety-enriched pouch/ sachet cutters to enhance the safety of the rework activity.

Generally, the proposed mitigating solutions in other industrial setups have targeted only a single issue, viz., cutting, squeezing, rolling, etc., (e.g., cutting in the garment industry, meat cutting in food processing FMCG, etc.). Rework of defective pouches/ sachets is peculiar to the personal care FMCG sector, and this rework activity comprises the combination of cutting, squeezing, and collecting the recovered liquid content. Unlike the current research outcome, the combination of all these aspects together has not been addressed by means of a single innovative solution, and as per the demand of varied scales of production levels.

As rework in the FMCG sector is carried out in many developing countries, and similar scenarios prevail, the developed tools have a broad market value among these FMCG manufacturing units, and the product is commercially viable. The developed tools can eliminate safety issues prevailing in pouch/ sachet cutting rework activity and eliminate drudgery. It leads to reduced man-day losses and worker compensation incurred due to accidents and injuries. These tools are easy to operate, maintain, and handle. Thus, these innovative tools can benefit the industrial stakeholders a lot.

Contribution to the society

The current research has the potential to directly impact the well-being and safety of thousands of shopfloor workers engaged in rework activity that is prone to the inherent risks of cuts and injuries. It may generate a sense of security and be cared for by their factory management, and it may further build enhanced mutual trust among the employer-employee. Such studies may motivate the factory management to take up more such studies to improve the shopfloor working conditions and remain productive by enhancing employee morale.

The other researchers in the ergonomic field may also be encouraged to provide ergonomic design interventions as mitigating solutions by employing a systematic design approach, and they will not be limited to diagnosing and ascertaining the MSDs only and subsequent reporting.

Aligned with the 'Zero Accident Vision' (Zwetsloot et al., 2017; Javed et al., 2021; Ahamad et al., 2022; OSHA, 2023), such practical studies on the industrial shopfloor help promote the philosophy and prove to be a proactive approach toward the advocates of this philosophy. It will be a major boost towards achieving this philosophy's bold vision and mission and will motivate others to take up such research to accomplish it in record time.

7.6 Limitations and Future Scope of Work

As there lies a paucity of research about FMCG work from an ergonomics perspective, the researcher has strived hard to steer the present study cautiously and took sufficient care in exploring, designing, developing, and testing the innovative tools/ apparatus in the best way possible. Still, the current research is prone to several limitations and shortcomings. A few of such limitations are discussed below, and the future scope of work is determined thereof:

- It is an in-depth field study based on the FMCG manufacturing units in northeastern India, particularly Assam. It is geographically bound to the limitations and working conditions that prevail in such manufacturing units. It has not explored the working conditions in the FMCG manufacturing units located in other parts of India. More new insights may have been gathered if those had been considered in this study.
- The current study has provided the mitigating solution in the form of a design intervention, i.e., an innovative pouch/ sachet cutter. It has not considered/ attempted to provide other types of mitigating solutions, viz. managerial solutions, behavioral solutions, engineering solutions, etc. Other solutions might be considered, and the approach towards their implementation may be explored further.
- The present study focuses on mitigating the 'after the fact' event occurrence, i.e., the situation arising after the pouch/ sachet gets defective and needs to be reworked. Efforts can be made to devise methods to minimize the event occurrence and its associated negative consequences, i.e., methods to reduce the pouch/ sachet defects and subsequent rejection. In fact, the sources leading to the event occurrence can be explored and curbed on a priority basis.
- Only the personal care goods (hair oil, serum, shampoo pouch/ sachets) were considered in this study. The FMCG segment covers other products filled in pouches/ sachets (jams, jellies, pickles, etc.), which are prone to the same ill effects. The present innovative solution might not be feasible for reworking the pouch/ sachets containing different contents that have different physical properties (high viscosity, solid particulates, etc.). Explorations to devise innovative solutions for their reworking may also be explored.

- In the current study, during the field trial phase, the field trials were conducted with a limited number of workers (as per availability) and as per the time constraint. Field trials were conducted as per 2-hour shifts for the ease of experimentation and various other logistic reasons. However, industrial work usually comprises 8-hour shifts. Efforts can be made to conduct field trials for an entire 8-hour shift, and more workers may be engaged (if available) to enlarge the sample size and consequent data collection.

7.7 Conclusion

The presented research aims to address the safety-related issues prevailing on the shopfloor of Indian FMCG manufacturing units by designing and developing innovative design interventions for varying levels of production scale and associated attributes. Such innovative design interventions are designed and developed using design and ergonomic principles. To pursue this research, various phases and sub-phases were taken into consideration. Starting from the literature review and assessing the research gap in the purview of FMCG manufacturing, the existing conditions on FMCG shopfloor were keenly observed and reviewed. Those were categorized and scrutinized further to decide the most critical problem that needed immediate attention, and a mitigating solution was planned.

Rework of defective pouch/ sachet was found to be the most critical activity, as it was prone to cuts and injuries. It included working with sharp cutters/ blades with bare, slippery hands and required forceful manual squeezing. Three distinct innovative solutions in the form of safety-enriched pouch/ sachet cutters were developed for the context-specific needs of three factory units working under varying levels of production scale. The design and development of these three innovative tools/ apparatus were found effective in terms of productivity, enhancing safety, and usefulness for the shopfloor workers engaged in the rework activity.

This research has explored many OSH and productivity-related issues that prevail on the FMCG shopfloor and need immediate attention from researchers and other industrial unit stakeholders. The successful implementation of this research to address safety-related challenges of FMCG shopfloor has created awareness among factory workers and management about implementing ergonomic principles in the industry. The other researchers, industrial stakeholders, and others interested in promoting safety and well-being within industrial tasks may imitate and follow the methodology depicted in this current research to achieve their objectives. As this research methodology is well-depicted in a meticulous form moving forward in phases and sub-phases, it can be replicated easily by the researchers and others in an easy manner to cater to the needs of other issues prevailing in varied domains of industrial work.

Overall, it may be concluded that the current research is pioneering and novel work in the domain of FMCG manufacturing and related research, especially in an ergonomic context. It has successfully demonstrated the use of ergonomic and design principles to devise context-specific innovative solutions to the safety-related issues/ challenges that exist within the manufacturing operations and has proposed such solutions even for the varying levels of the production scale and associated needs. It is quite an appreciable attempt that paves the way for devising standardized solutions for non-standardized work activities. It may motivate the OEMs to thoroughly look into the requirements of industrial activities that often remain neglected and need their attention and standardized devices/ tools/ apparatuses.

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APPENDIX – A.1

Institute Human Ethical Committee Approval

Institute Human Ethics Committee
INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
North Guwahati, Guwahati – 781 039

Institute Human Ethics Committee Approval

The chair and the members of Institute Human Ethics Committee of Indian Institute of Technology Guwahati have considered the project titled "**Ergonomic design interventions for improvement of shop floor working conditions in Indian fast moving consumer goods (FMCG) manufacturing industries (tentative)**" in the meeting convened on 28th February 2020 and given its approval for the same.

V Katiyar 31/8/2020

Prof. Vimal Katiyar
Deputy Chairperson of IHEC &
Dean R&D, IITG

संकायाध्यक्ष, अनुसंधान एवं विकास
Dean, Research and Development
भारतीय प्रौद्योगिकी संस्थान गुवाहाटी
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APPENDIX – A.2

Non-disclosure Agreement (NDA)

Dr. Sougata Karmakar
Associate Professor
Department of Design

भारतीय प्रौद्योगिकी संस्थान गुवाहाटी
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DEPARTMENT OF DESIGN

To
The HR Manager ,
[redacted]

Date: 03.04.2018

Sub: Request for permission to carry out research work in the factory of [redacted] Limited, Guwahati

Dear Sir,
We understand that you are one of the reputed producers of a wide range of high quality daily-care and life-care products in India. We are planning to conduct a research leading to Ph.D thesis with an aim to optimize the production process and packaging in your factories from an ergonomic perspective for enhanced productivity and increased efficiency.

Our study aims at detecting from an ergonomic perspective the several key performance indicators lowering down the production output viz. repetitive work processes, idle time, bottlenecks in material flow, underutilized workstations requiring excessive manpower utilization etc. using time-motion studies, CAD simulation, investigating shop-floor layout etc. We will propose the feasible low cost Ergonomic Design Interventions for improving process planning, shop-floor layout, and betterment of occupational health of the workers. We will also check the feasibility of semi-automation of such labour intensive workstations towards enhancement of the productivity.

For conducting this research, we require the access to your office and production and packaging area of the factory. We need your permission to interact with the workers, photography and videography of the various operations in the shop-floors under the purview of research study. Such access is required once in a month for the period of one year so that low cost Ergonomic Design Interventions may be implemented and enhancement of productivity can be assessed.

We shall be very much thankful to you if permission could kindly be granted to carry out the above mentioned research in your factory at Guwahati, India.

Non-disclosure Agreement (NDA)

Dr. Sougata Karmakar
Associate Professor
Department of Design

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DEPARTMENT OF DESIGN

We would like to give an undertaking on the following aspects related to this research.

- Name of the company will not be mentioned in any of the literatures.
- Photography and Video recording depicting the name of the company in any of the company asset will not be published.
- Any information regarding product, process will be first shown to the factory management before recording or publishing.
- In no case objectionable information (if any) related to company business will be published or shared with third party.
- We understand that permission if granted is solely for educational purposes only.
- Results of the research work will be shared with the company for its benefit.

Yours truly,

3/4/18

Mr. Gurdeep Singh
Research Scholar,
Department of Design,
Indian Institute of Technology Guwahati, Guwahati, Assam – 781039.
Mob: [redacted]

Sougata Karmakar 03.04.18
Dr. Sougata Karmakar (Ph.D Supervisor),
Associate Professor,
Department of Design,
Indian Institute of Technology Guwahati, Guwahati, Assam – 781039.
Ph: [redacted]

APPENDIX – A.3

Participant Information Sheet

Participant Information Sheet

Name of the Department: Design Department, IIT Guwahati

Study Title: Ergonomic Design Interventions for improvement of shop-floor working conditions in Indian Fast Moving Consumer Goods (FMCG) manufacturing industries.

Subjects involved in the study: Employees of concerned Indian FMCG manufacturing Industries.

Invitation to participate in the study:

We would like you to take part in our research study. Please read the instructions carefully and understand. If the information is not clear, feel free to ask. You can take time to decide whether you are willing to take part in the study.

Purpose of the Study: Field Survey - to collect critical information pertaining to the existing shop floor scenario for understanding the pain/ frustration points of the workers (occupational health and safety aspects and ergonomic stressors), and bottle-necks to their productivity.

Selection of the employees:

You (employees of the factory) are selected for the study as the results of the current study will positively affect your occupational well-being and will enhance your occupational health and safety.

What will you be asked to do?

You will be interviewed to collect information on the following:

1. General demographic data
2. Work history
3. Routine activities at workstations
4. General aspects of these workstations
5. Prevalence of musculoskeletal symptoms
6. Psycho-social characteristics
7. Cognitive workload assessment using the NASA Task Load Index

Photography of the interview and shop floor activity within industrial premises will be taken to support the study and for documentation.

What will happen to the information when this study is over?

The data will be kept for three years after the study is published, and then it will be deleted and destroyed.

Do you have any Questions?

Contact Details:

Ph.D. Research Scholar:	**Faculty Member:**
Gurdeep Singh Department of Design Indian Institute of Technology Guwahati Email: singh176105105@iitg.ac.in Mob: [redacted]	Dr. Sougata Karmakar Associate Professor, Department of Design Indian Institute of Technology Guwahati Email: karmakar.sougata@iitg.ac.in Mob: [redacted]

APPENDIX – A.4

NASA Task Load Index (TLX) Rating Scale

(Source: Hart and Staveland, 1988)

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

APPENDIX – A.4

NASA TLX – Rating Scale Definitions

(Source: Hart and Staveland, 1988)

Title	End Points	Description
Mental Demand	Low/ High	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand	Low/ High	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand	Low/ High	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance	Good/ Poor	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort	Low/ High	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration Level	Low/ High	How insecure, discouraged, irritated, stressed, and annoyed versus secure, gratified, content, relaxed, and complacent did you feel during the task?

APPENDIX – A.4

NASA TLX – Sources of workload comparison charts

(Source: Hart and Staveland, 1988)

Effort or Performance	Temporal Demand or Frustration
Temporal Demand or Effort	Physical Demand or Frustration
Performance or Frustration	Physical Demand or Temporal Demand
Physical Demand or Performance	Temporal Demand or Mental Demand
Frustration or Effort	Performance or Mental Demand
Performance or Temporal Demand	Mental Demand or Effort
Mental Demand or Physical Demand	Effort or Physical Demand
Frustration or Mental Demand	

APPENDIX – A.5

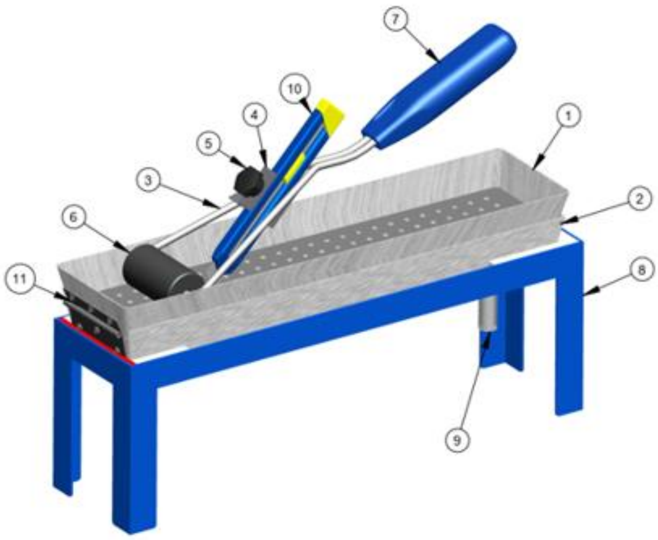
System Usability Scale (SUS)

(Source: adapted from Brooke, 1996)

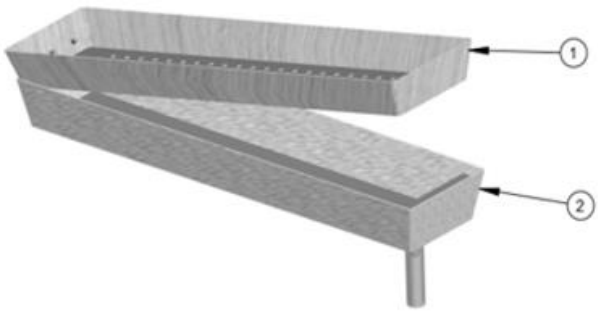
S. No.	Question	Strongly Disagree				Strongly Agree
1.	I think that I would like to use this tool/ apparatus frequently.	1	2	3	4	5
2.	I found the tool/ apparatus unnecessarily complex.	1	2	3	4	5
3.	I thought the tool/ apparatus was easy to use.	1	2	3	4	5
4.	I think that I would need the support of a technical person to be able to use this tool/ apparatus.	1	2	3	4	5
5.	I found the various functions in this tool/ apparatus were well integrated.	1	2	3	4	5
6.	I thought there was too much inconsistency in this tool/ apparatus.	1	2	3	4	5
7.	I would imagine that most people would learn to use this tool/ apparatus very quickly.	1	2	3	4	5
8.	I found the tool/ apparatus very cumbersome to use.	1	2	3	4	5
9.	I felt very confident using the tool/ apparatus.	1	2	3	4	5
10.	I needed to learn a lot of things before I could get going with this tool/ apparatus.	1	2	3	4	5

APPENDIX – A.6

Innovative Cutter for Factory A



INDEX	DESCRIPTION	QTY	MTL
1	Upper Tray	1	SS 304
2	Lower Tray	1	SS 304
3	Wire Frame	1	SS
4	Cutter Holder	1	SS
5	Knob	1	Plastic
6	Teflon Roller	1	Teflon
7	Plastic Handle with Rubber Grip	1	Plastic + Rubber
8	Base Frame	1	MS
9	Braidded Pipe	1	Plastic
10	Paper Cutter	1	Plastic
11	Hinge 3"	1	SS



INDEX	DESCRIPTION	QTY	MTL	RMKS
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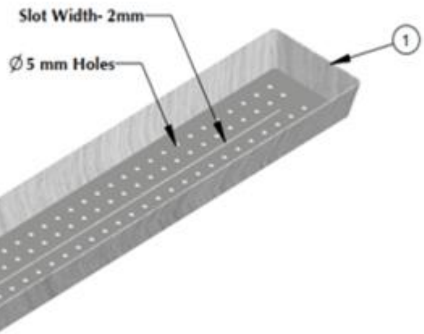
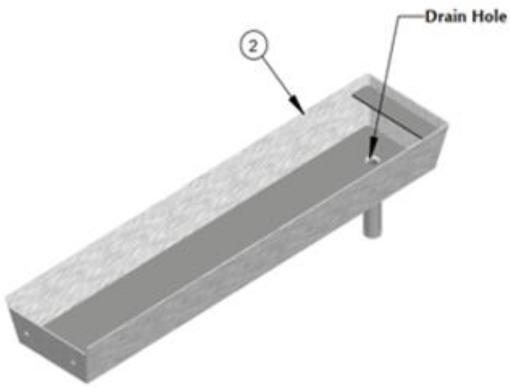
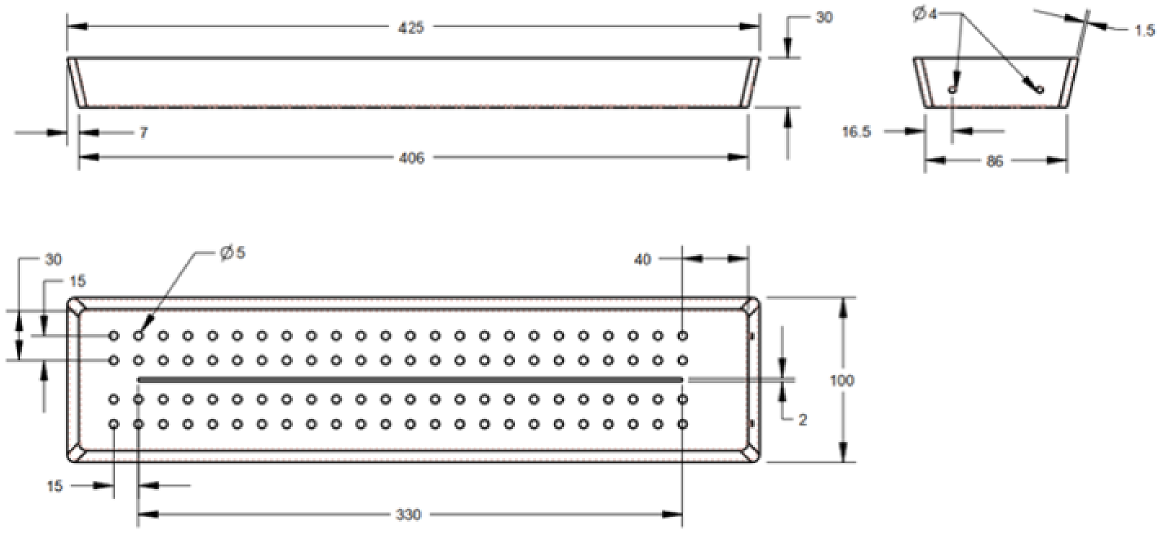
2	Lower Tray	1	SS 304	





Innovative Cutter for Factory A

Upper Tray:



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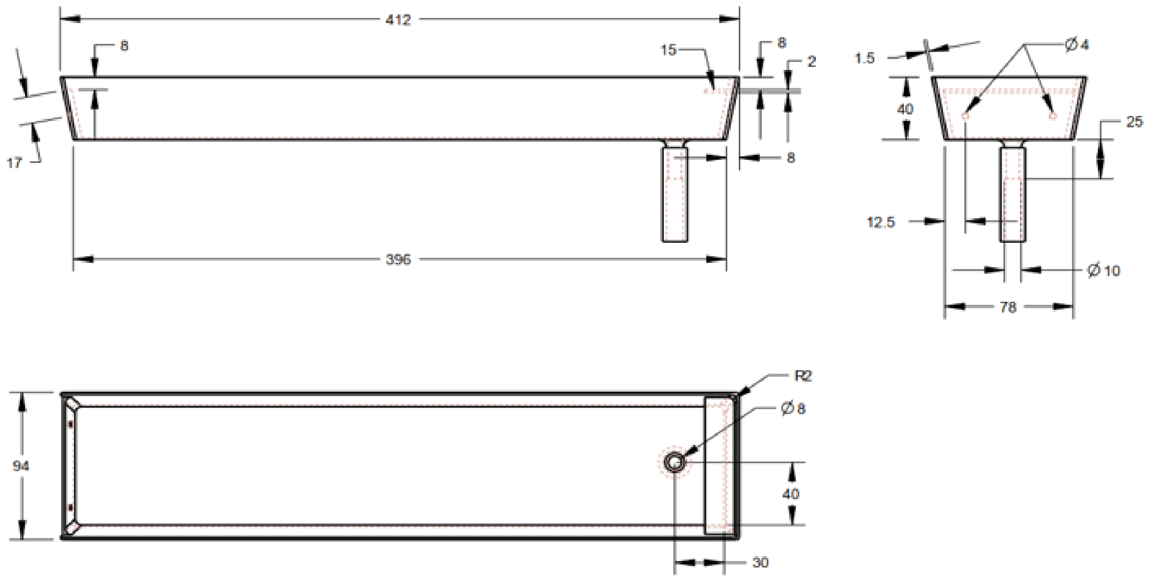
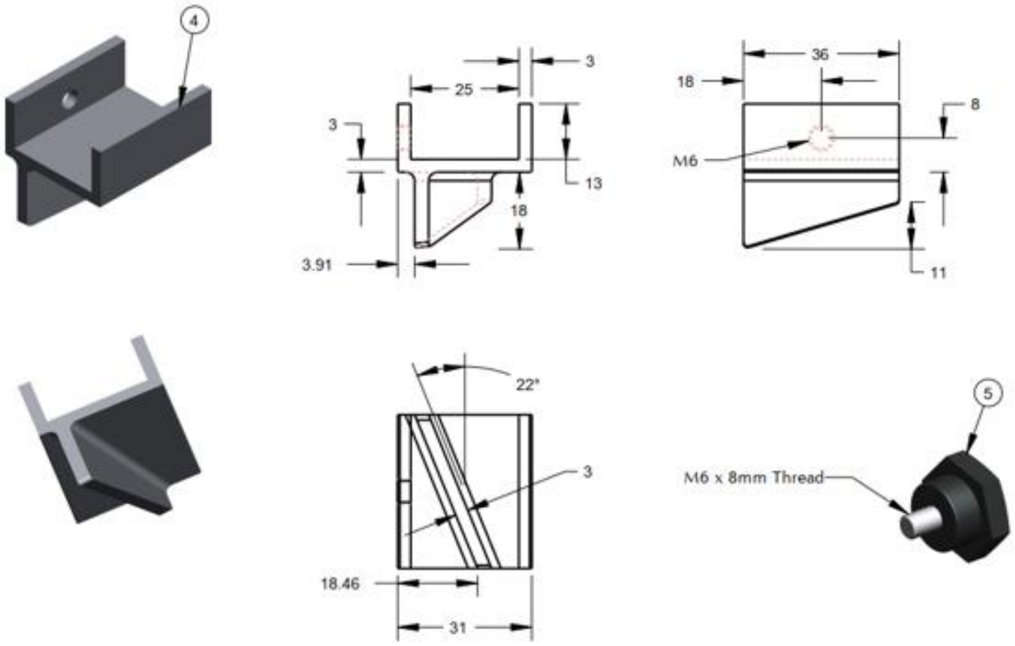
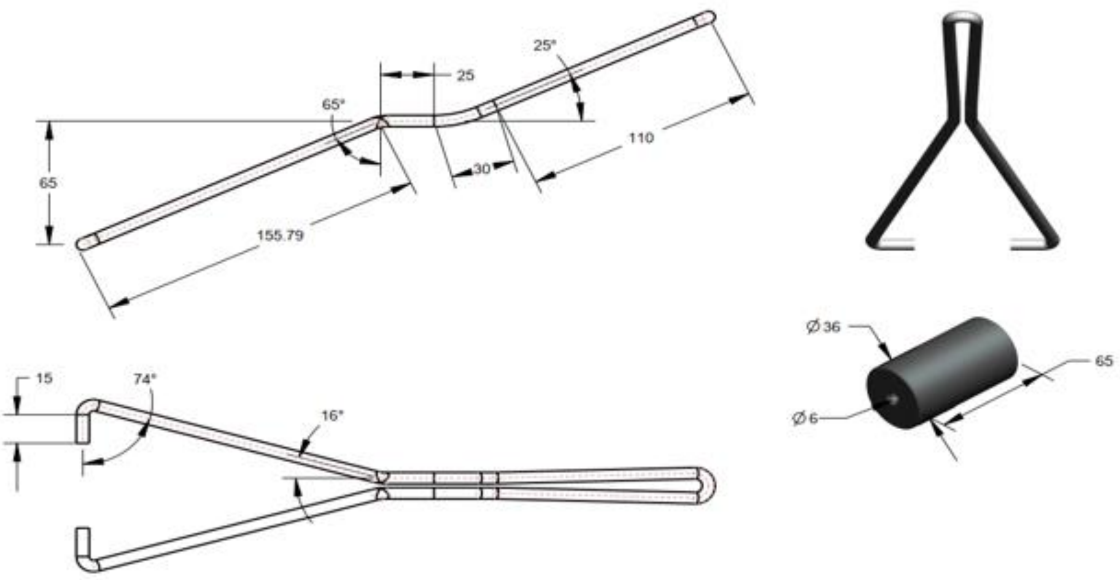


APPENDIX – A.6

Innovative Cutter for Factory A

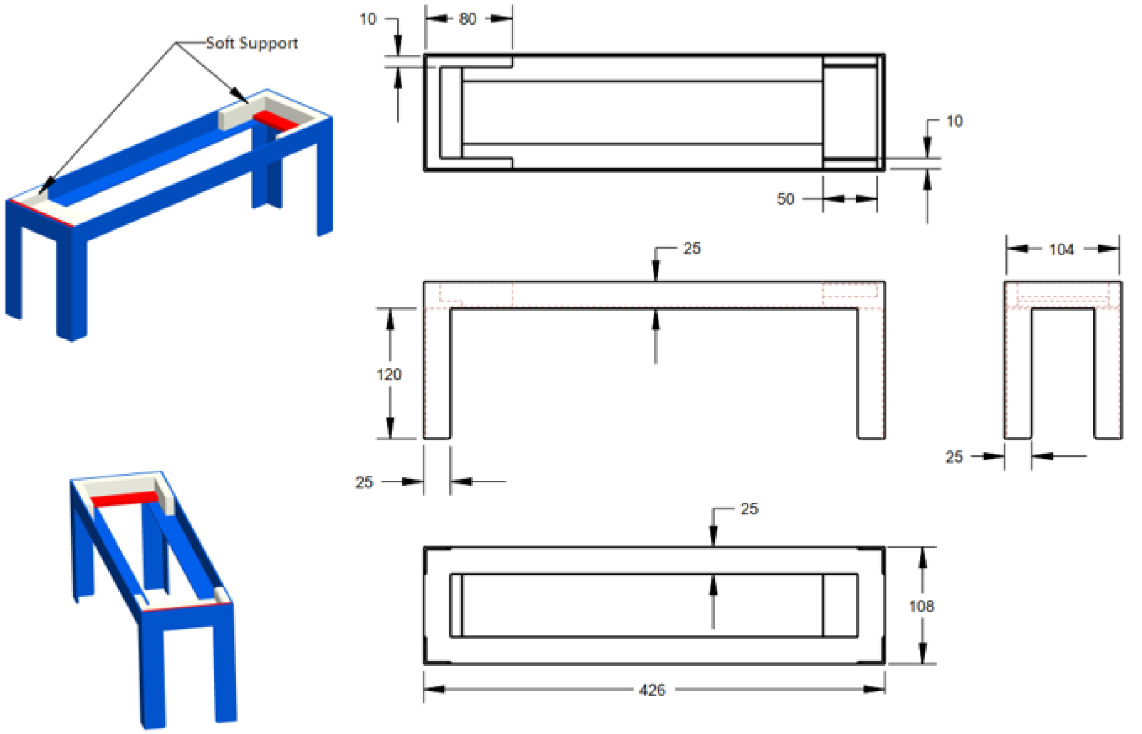
Cutter Holder:



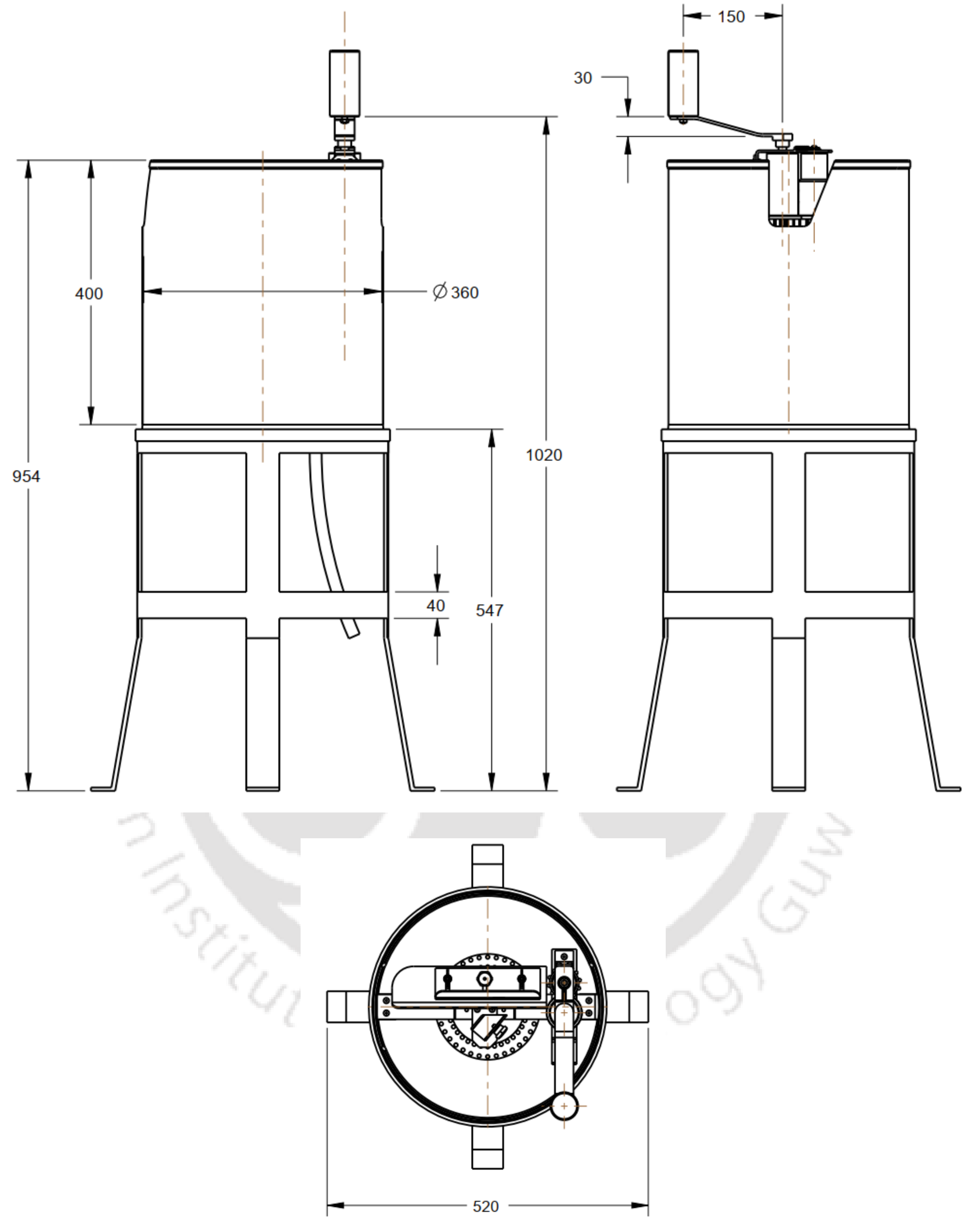


Innovative Cutter for Factory A

Base Frame:

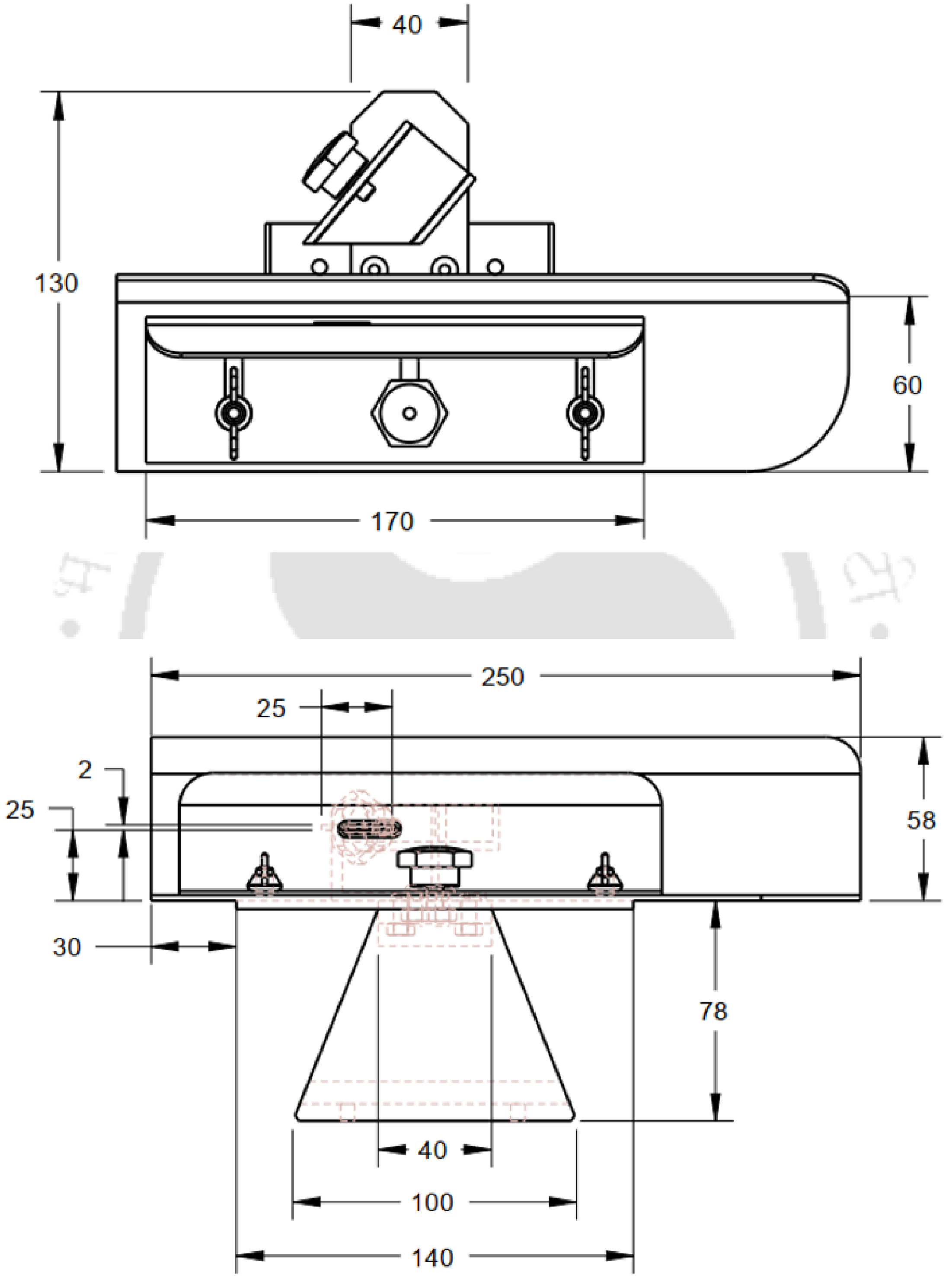


Innovative Cutter for Factory B



APPENDIX – A.7

Innovative Cutter for Factory B



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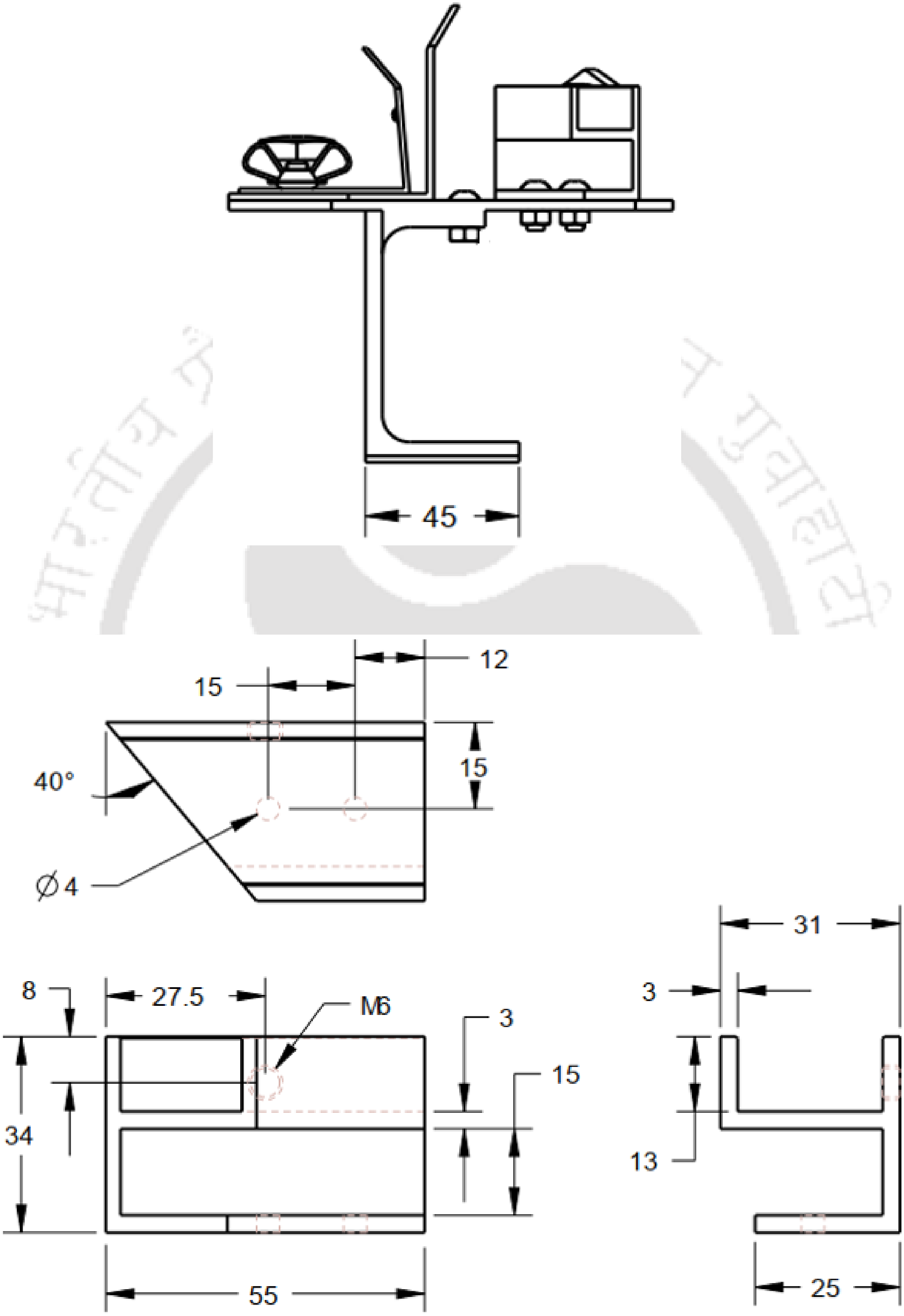
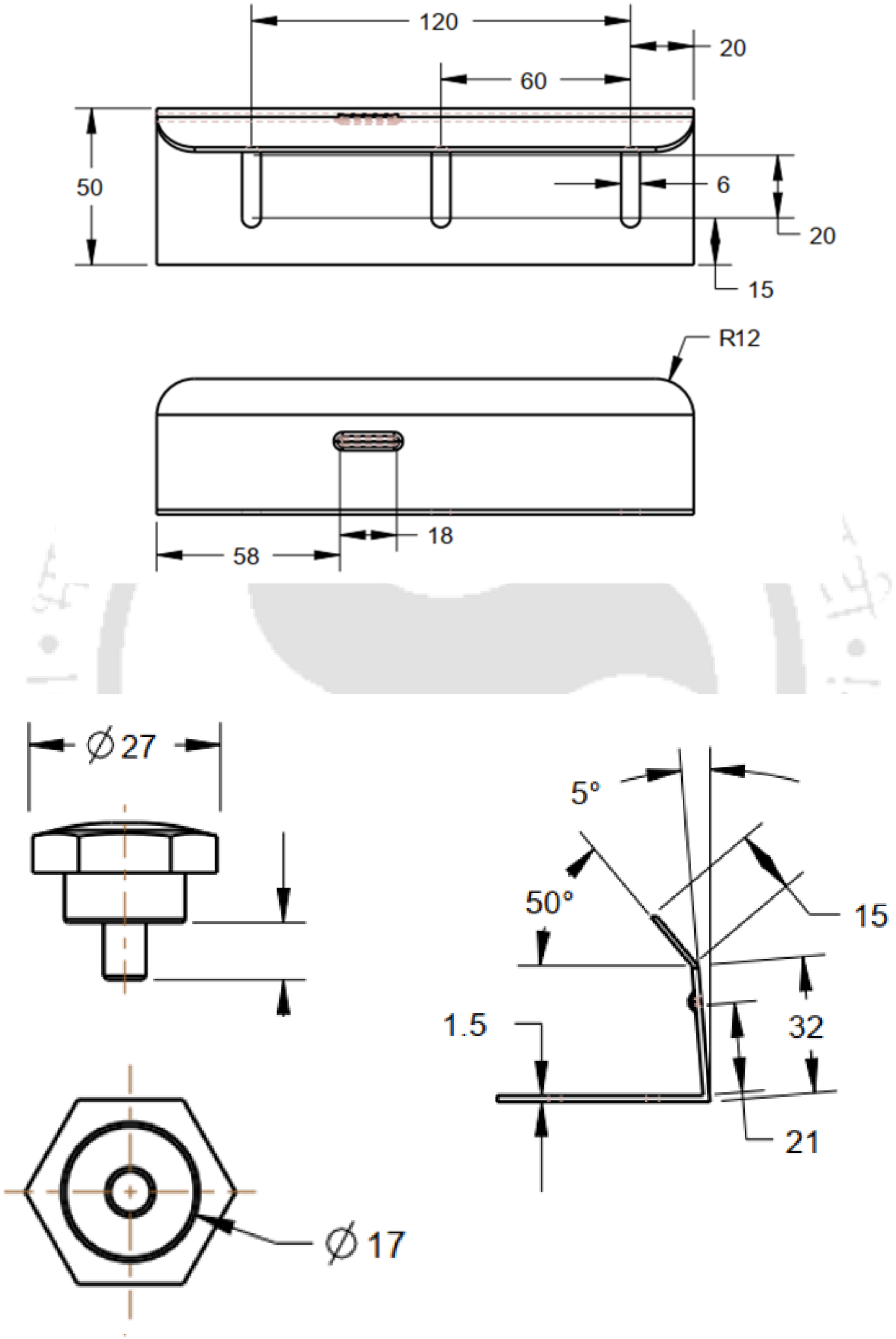


APPENDIX – A.7

Innovative Cutter for Factory B



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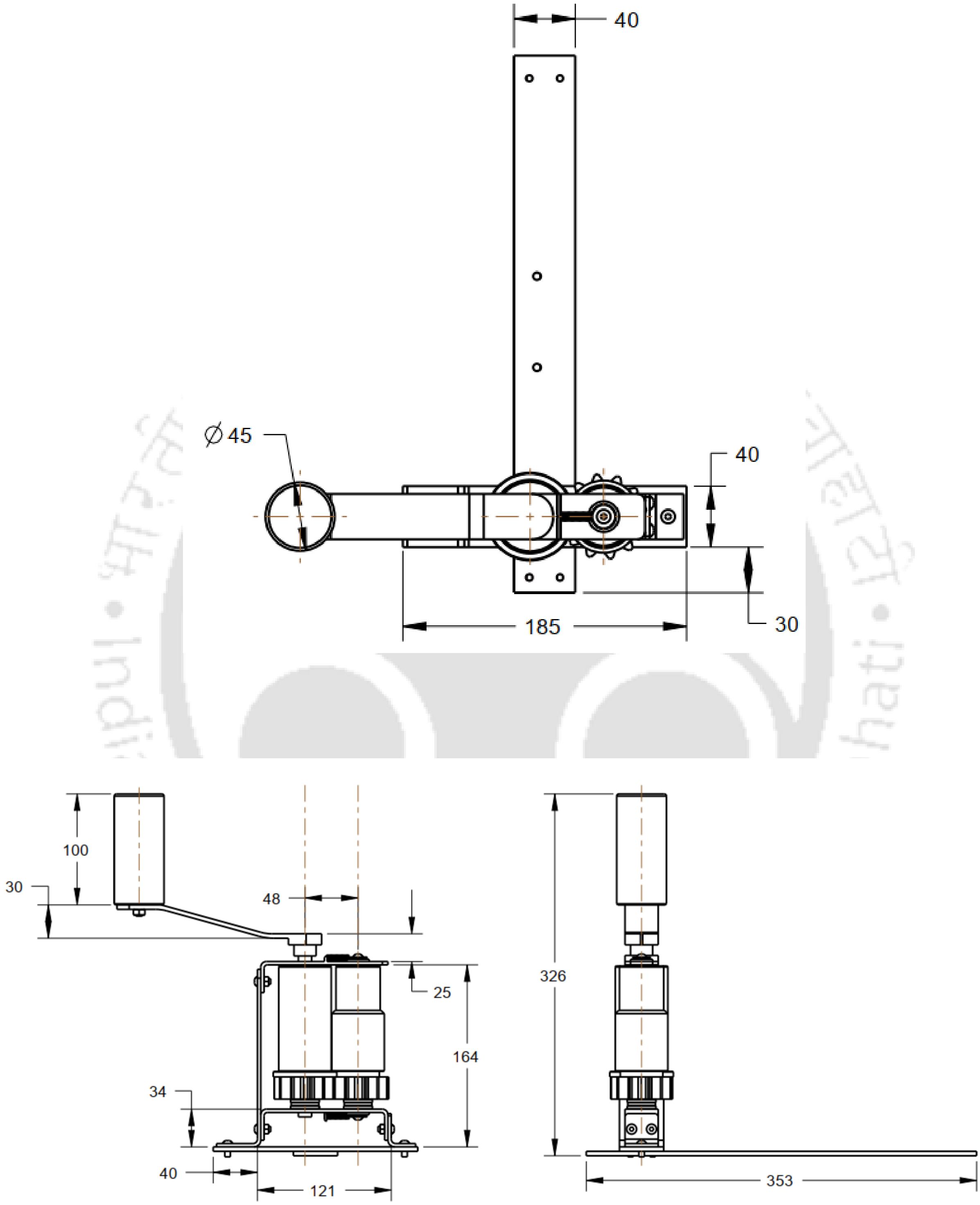
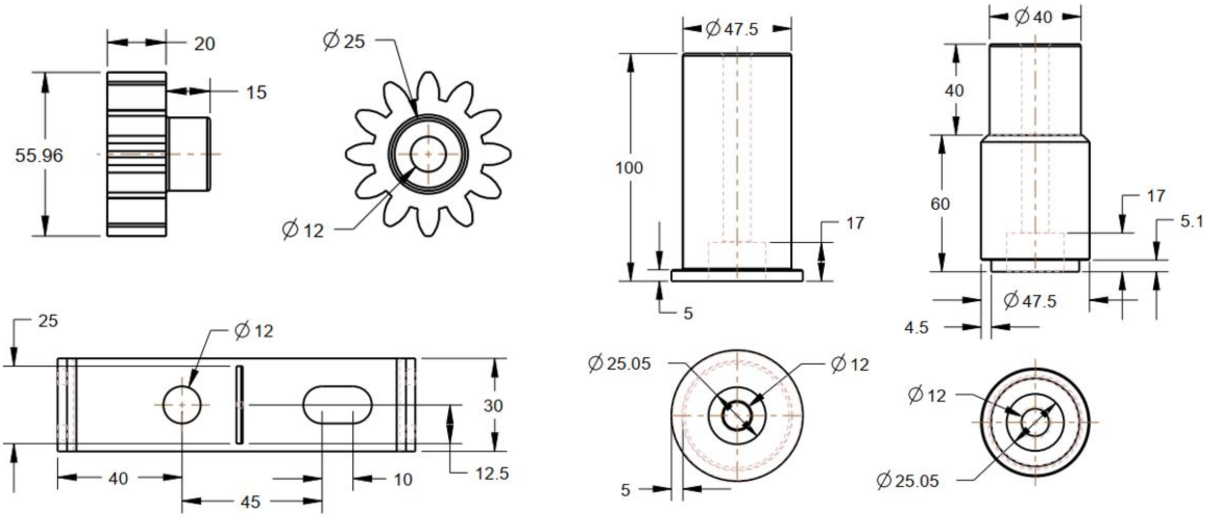
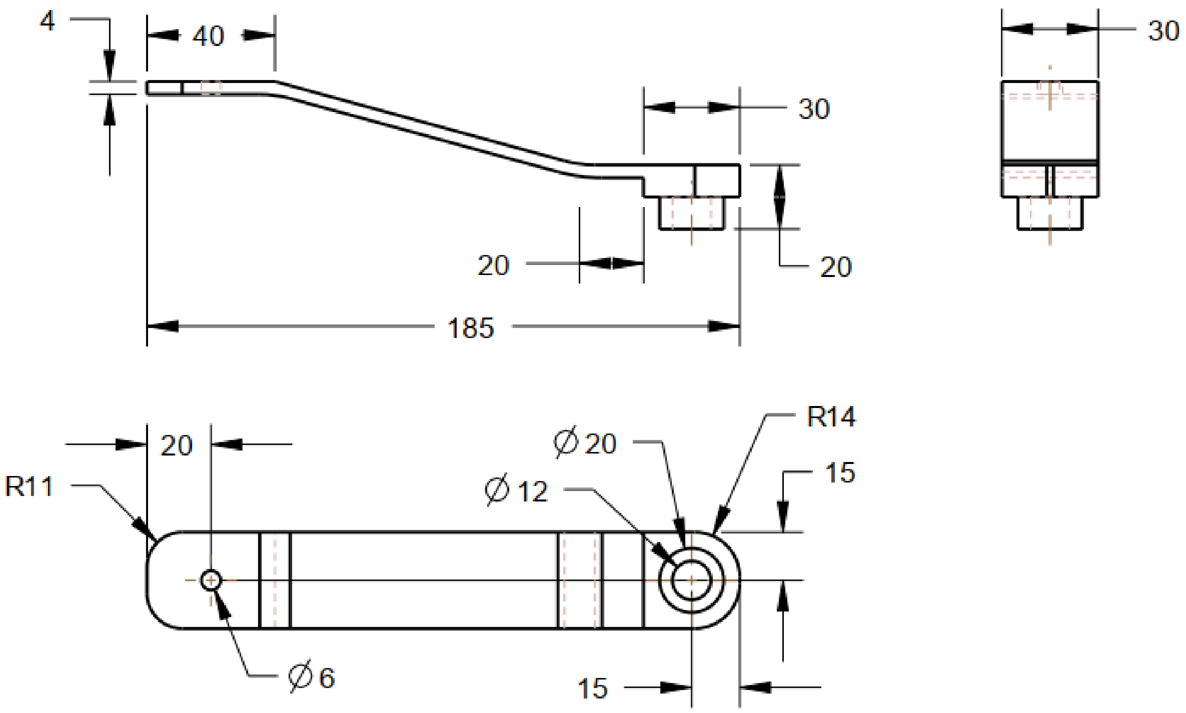


APPENDIX – A.7

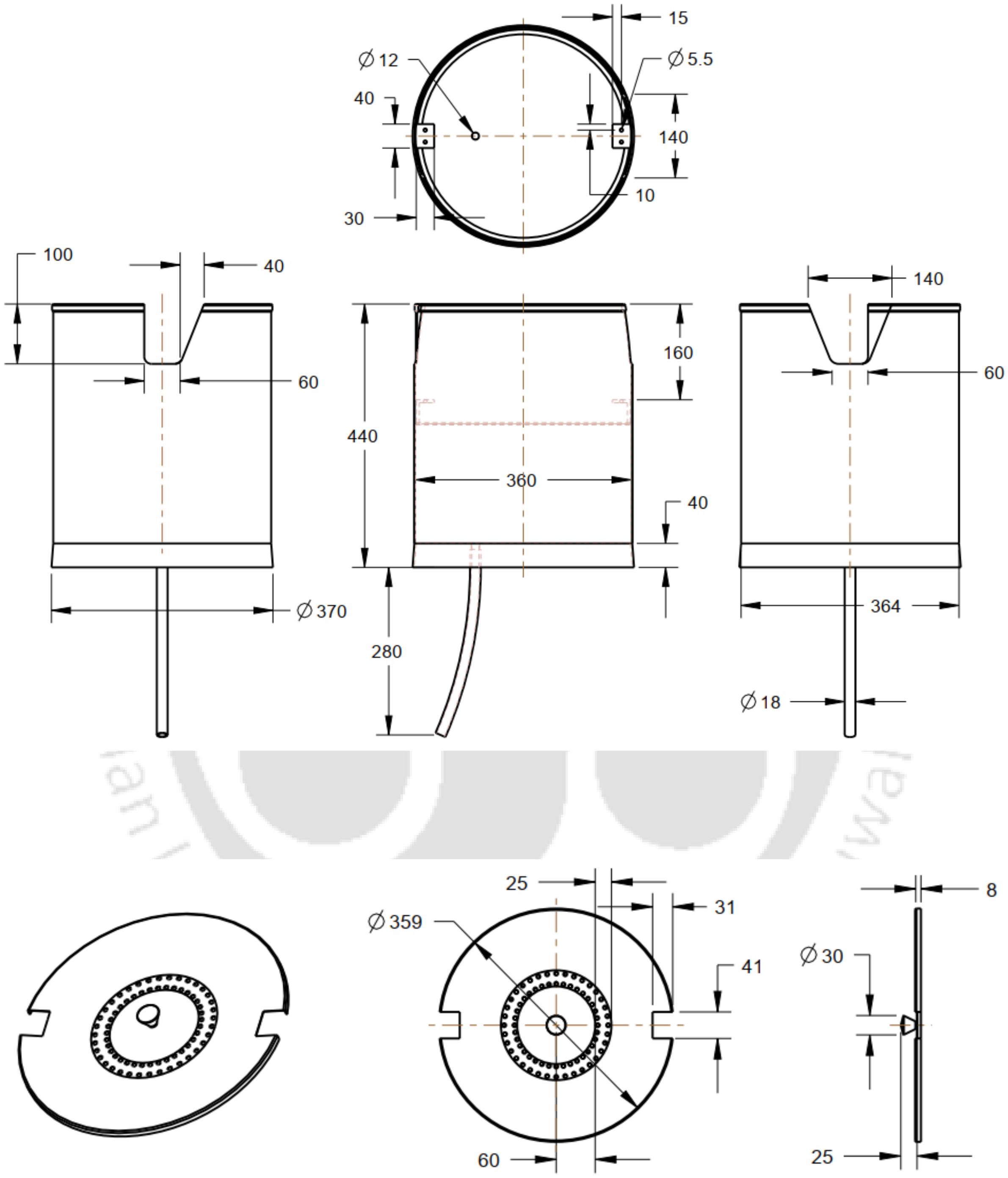
Innovative Cutter for Factory B





APPENDIX – A.7

Innovative Cutter for Factory B



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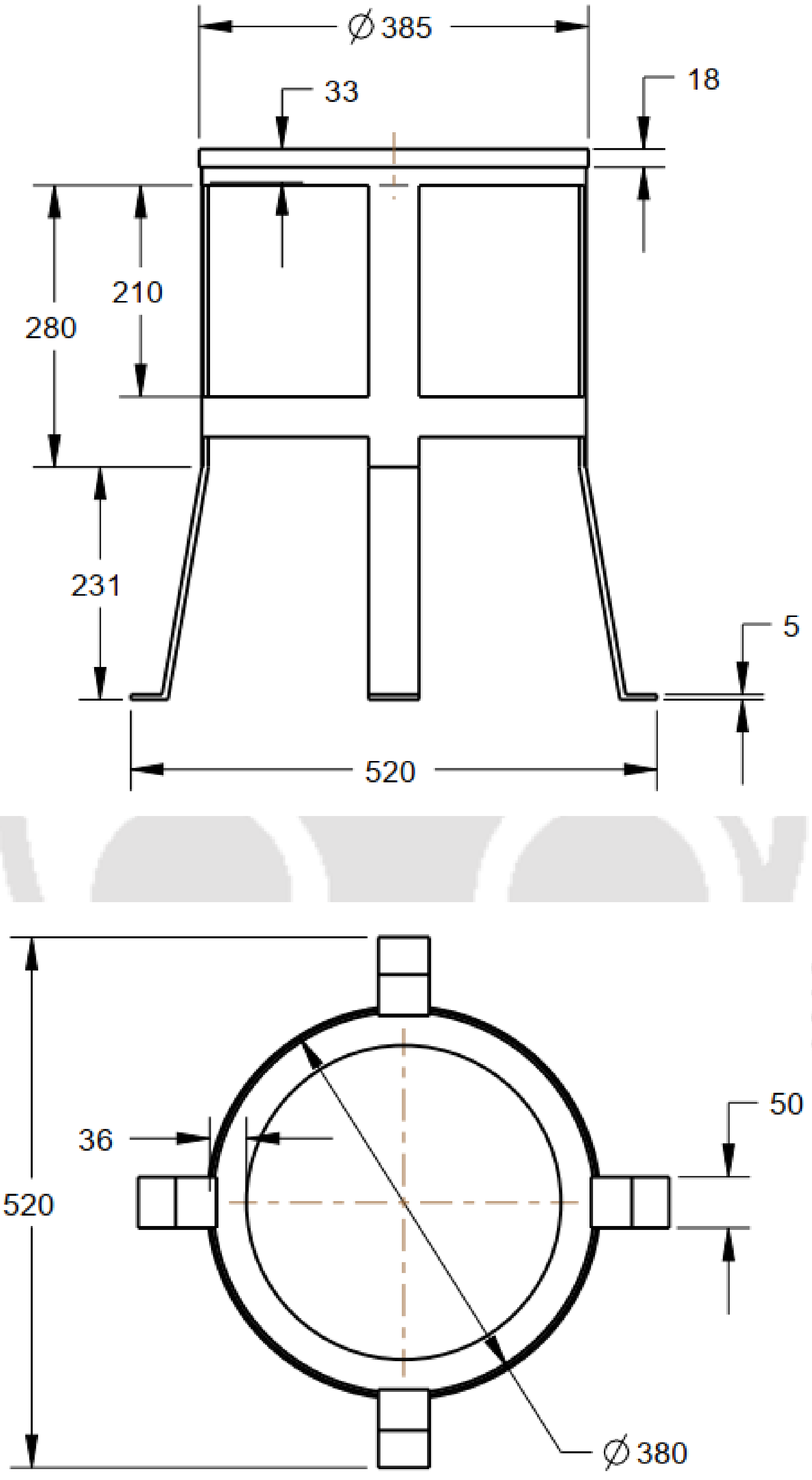
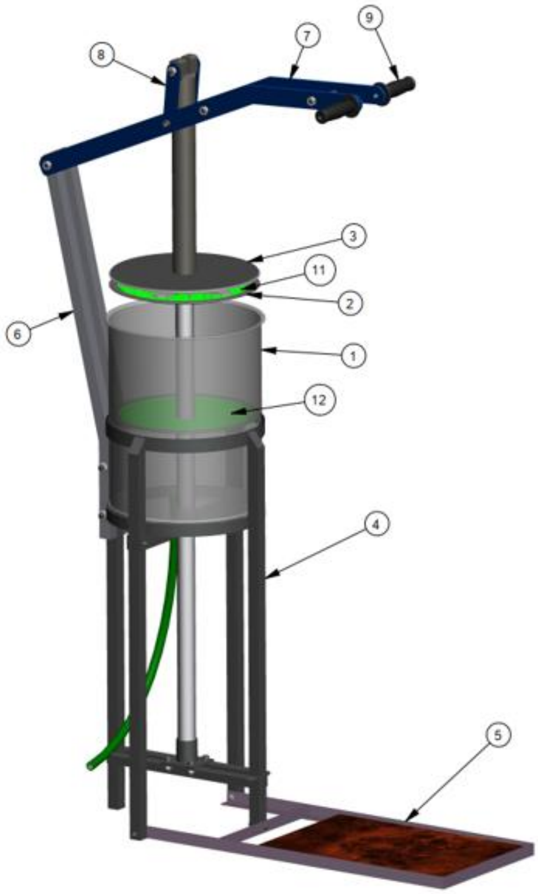
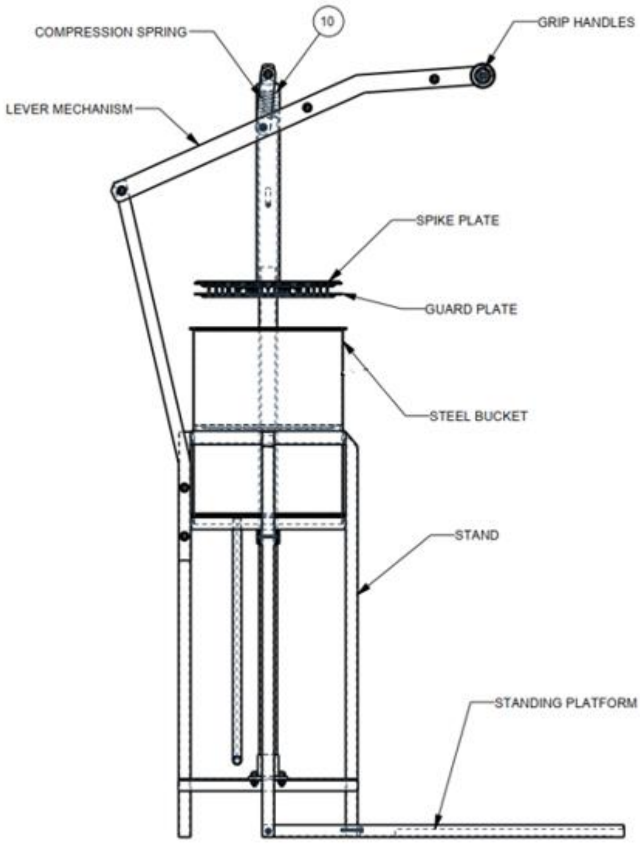


Innovative Cutter for Factory C

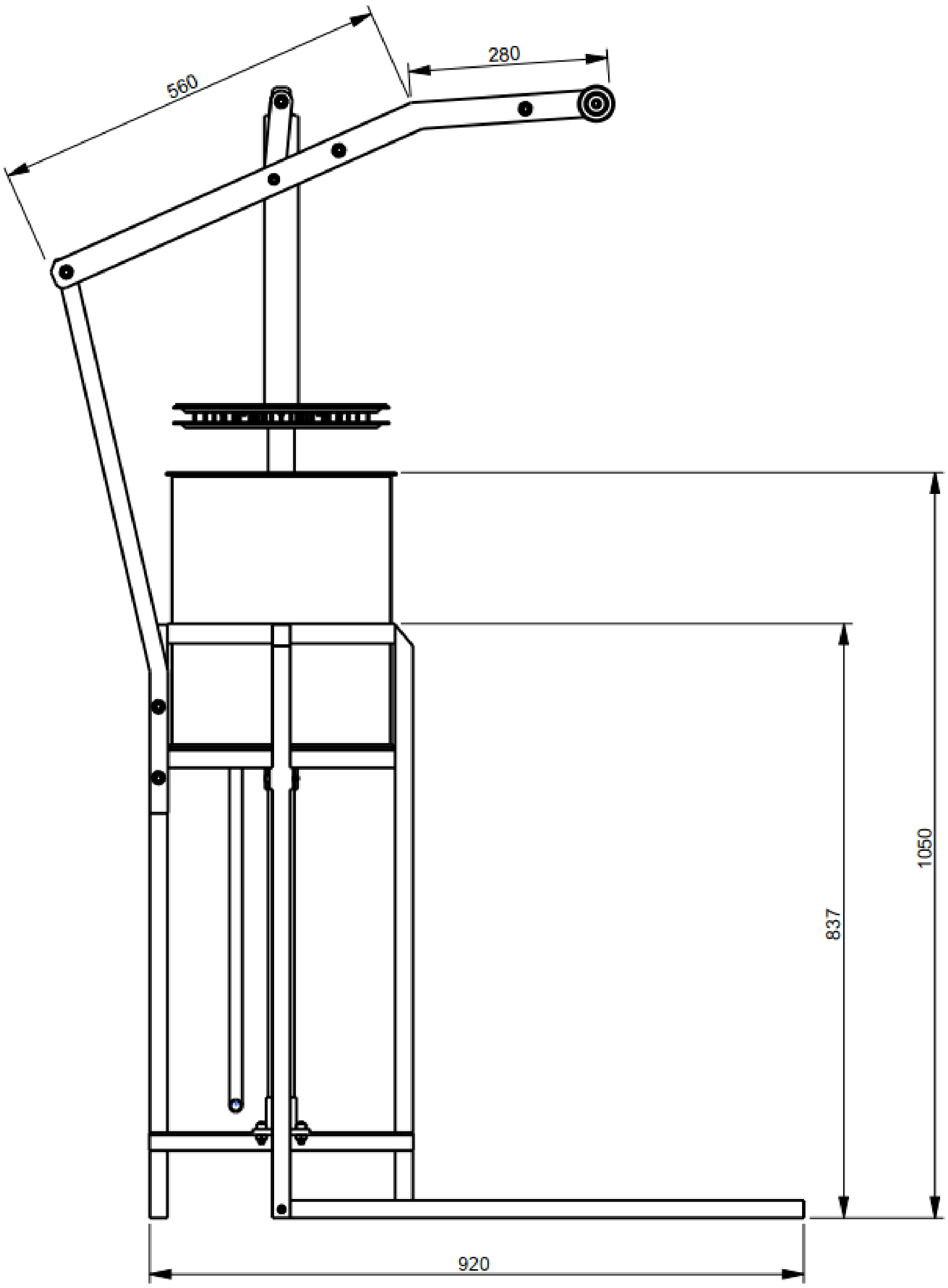




INDEX	DESCRIPTION	QTY	MATERIAL
1	BUCKET	1	S. STEEL
2	GUARD PLATE	1	S. STEEL
3	SPIKE PLATE	1	S. STEEL
4	STAND	1	STEEL
5	STANDING PLATFORM	1	STEEL + WOOD
6	FULCRUM LINK	2	STEEL
7	LEVER ARM	2	STEEL
8	CONNECTOR	2	STEEL
9	HAND GRIP	2	PLASTIC
10	COMPRESSION SPRING	1	S. STEEL
11	SPIKES	72	S. STEEL
12	POROUS PLATE	1	S. STEEL

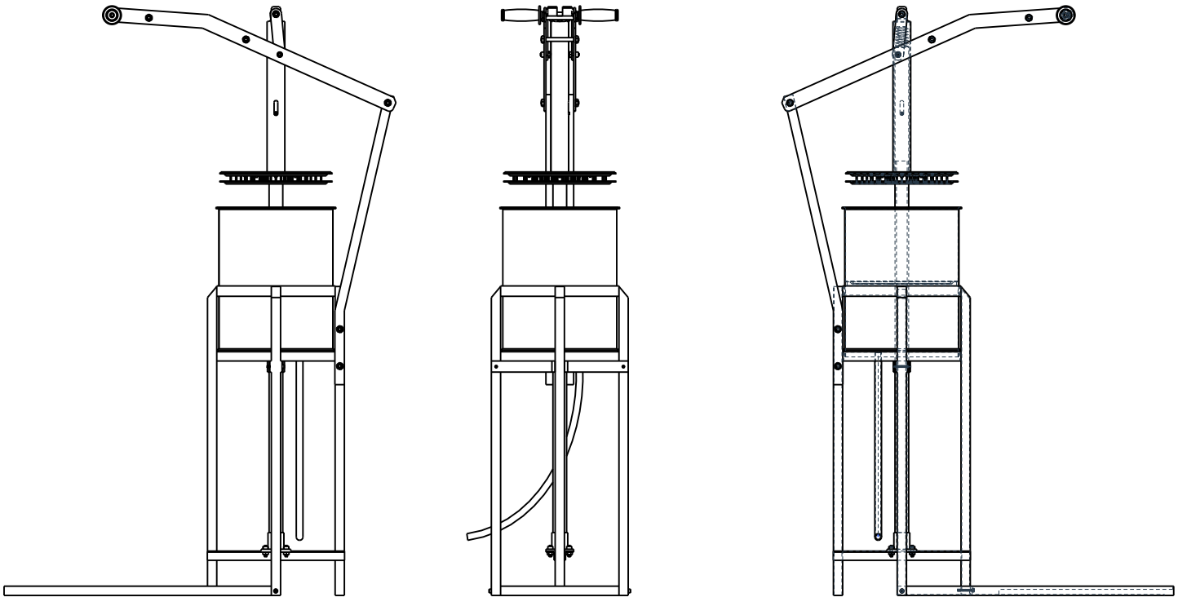
APPENDIX – A.8

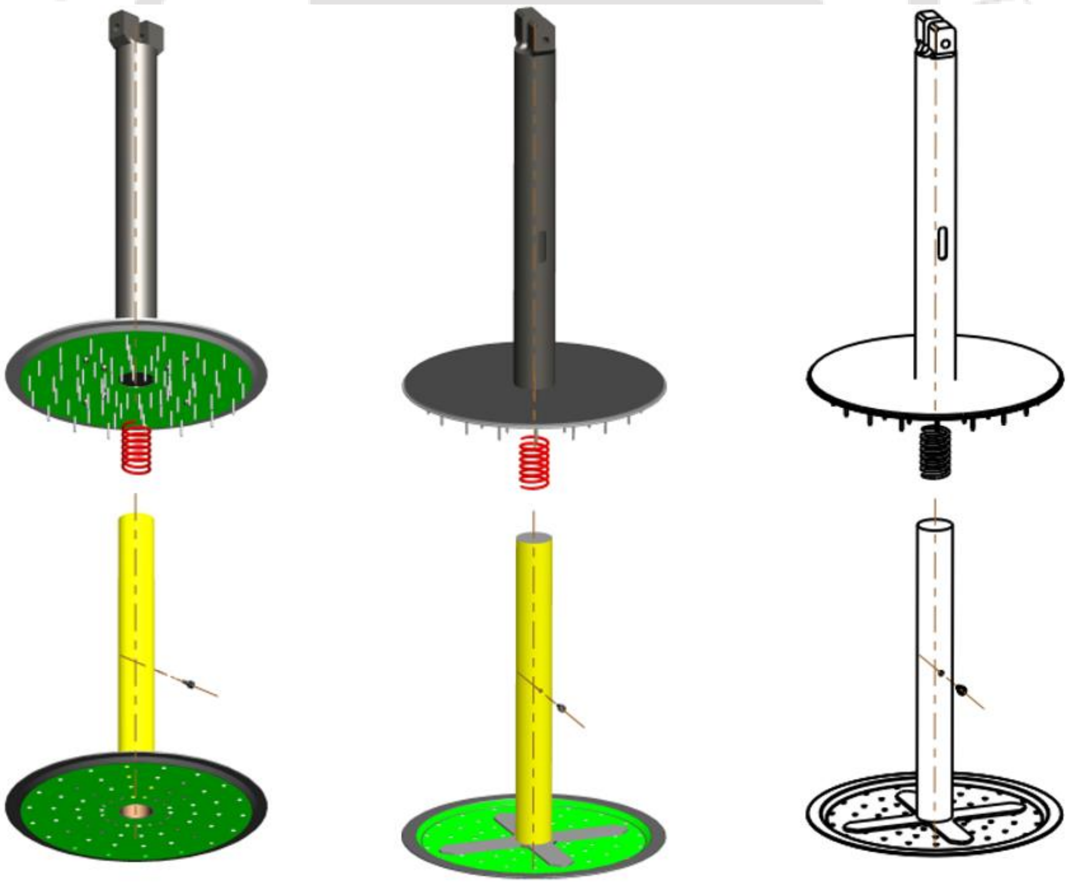
Innovative Cutter for Factory C



APPENDIX – A.8

Innovative Cutter for Factory C





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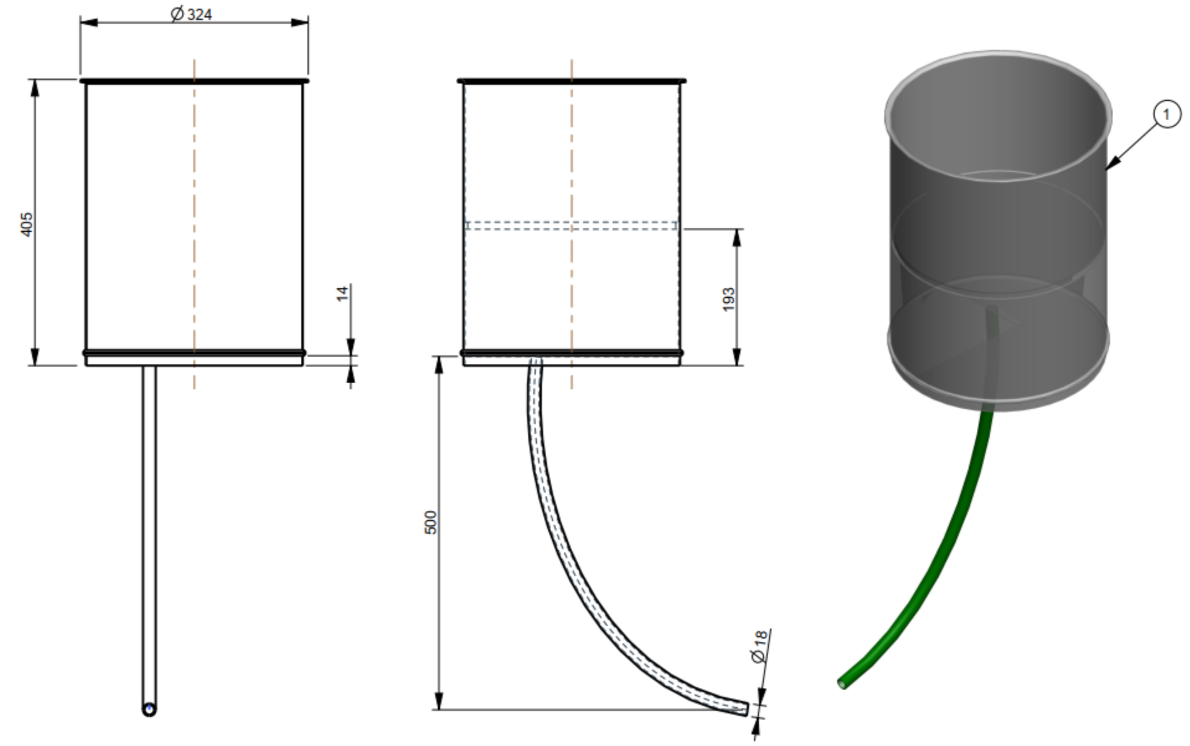

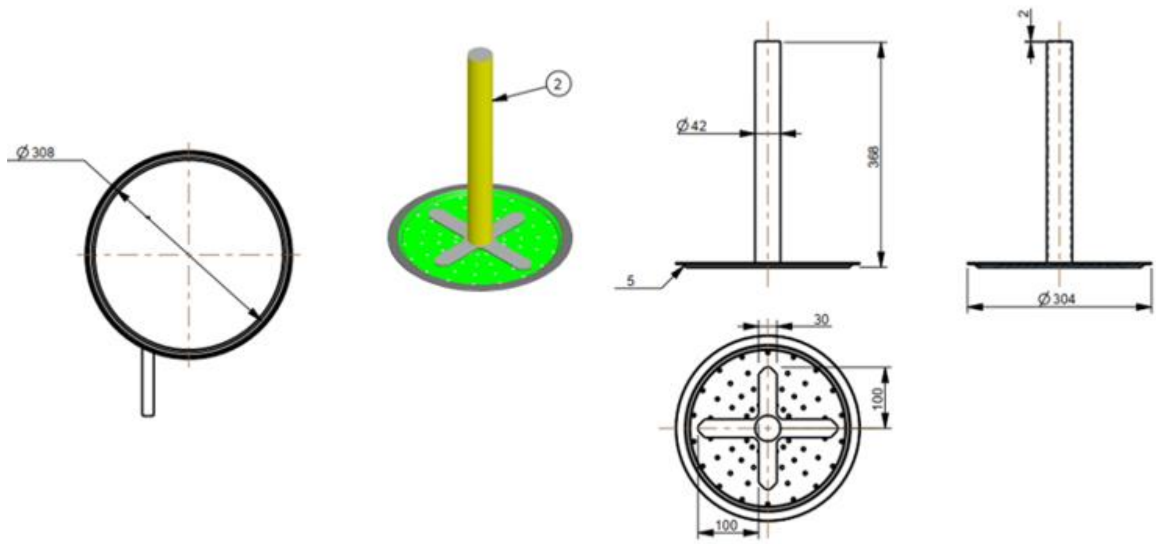

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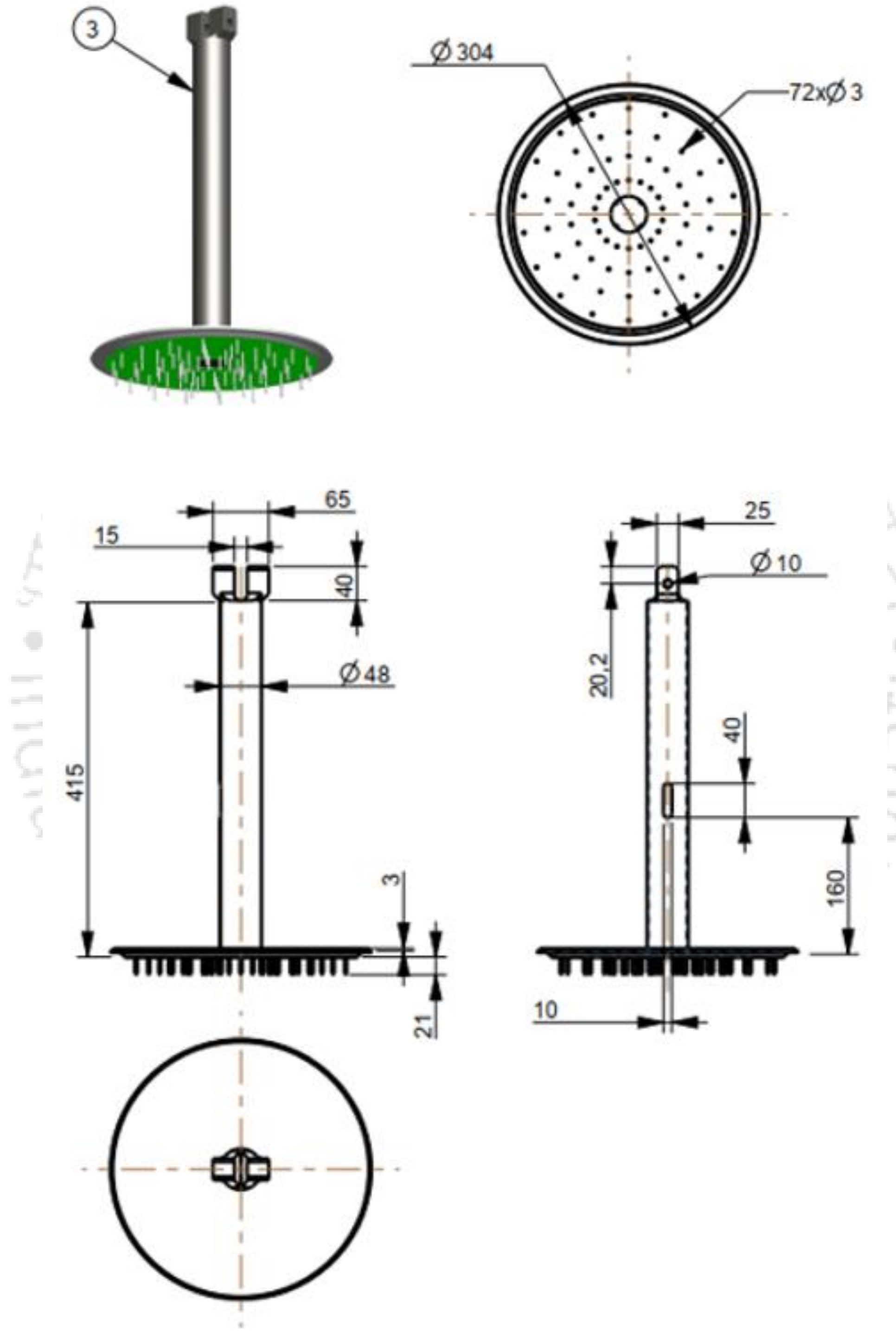
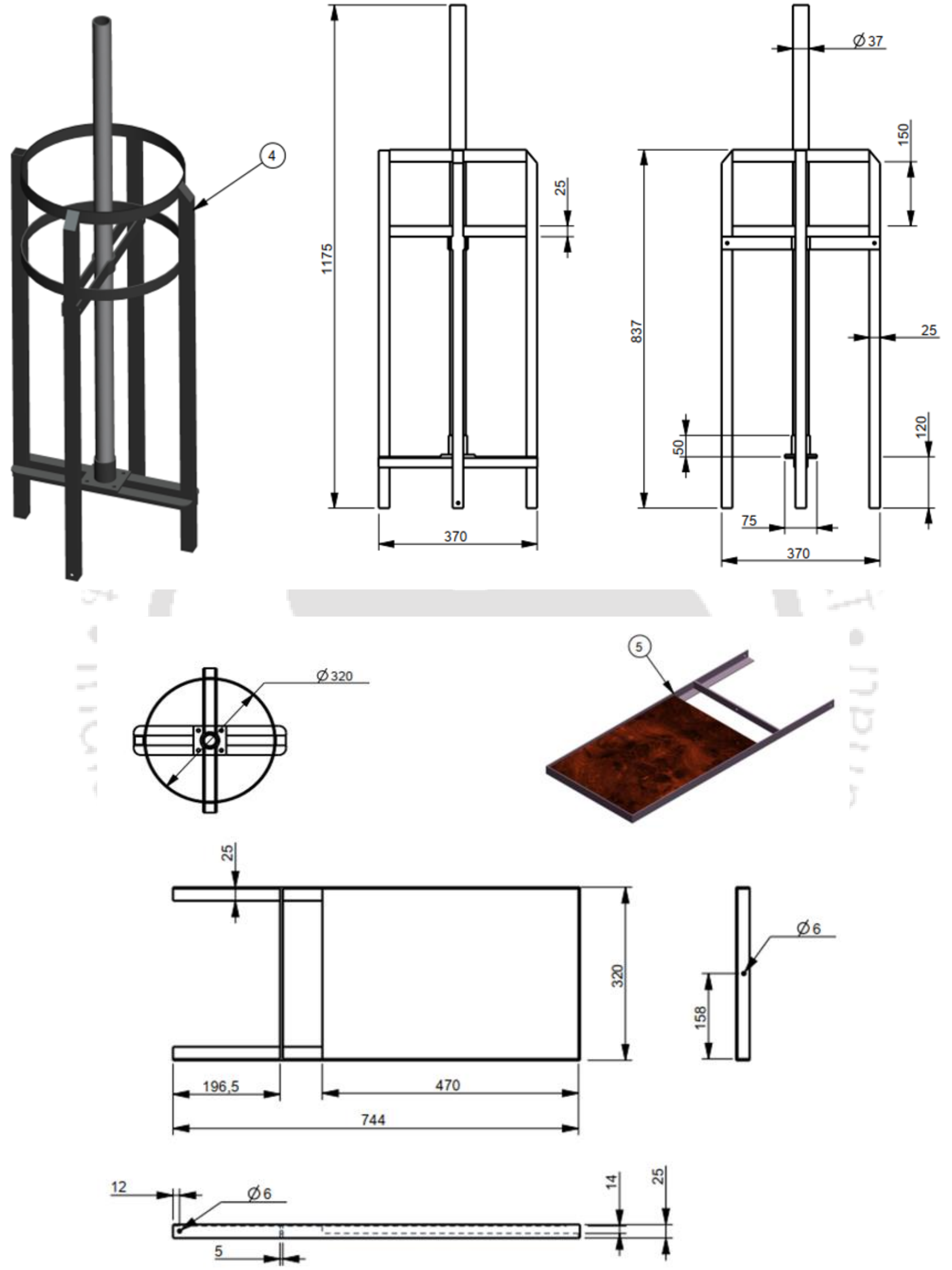


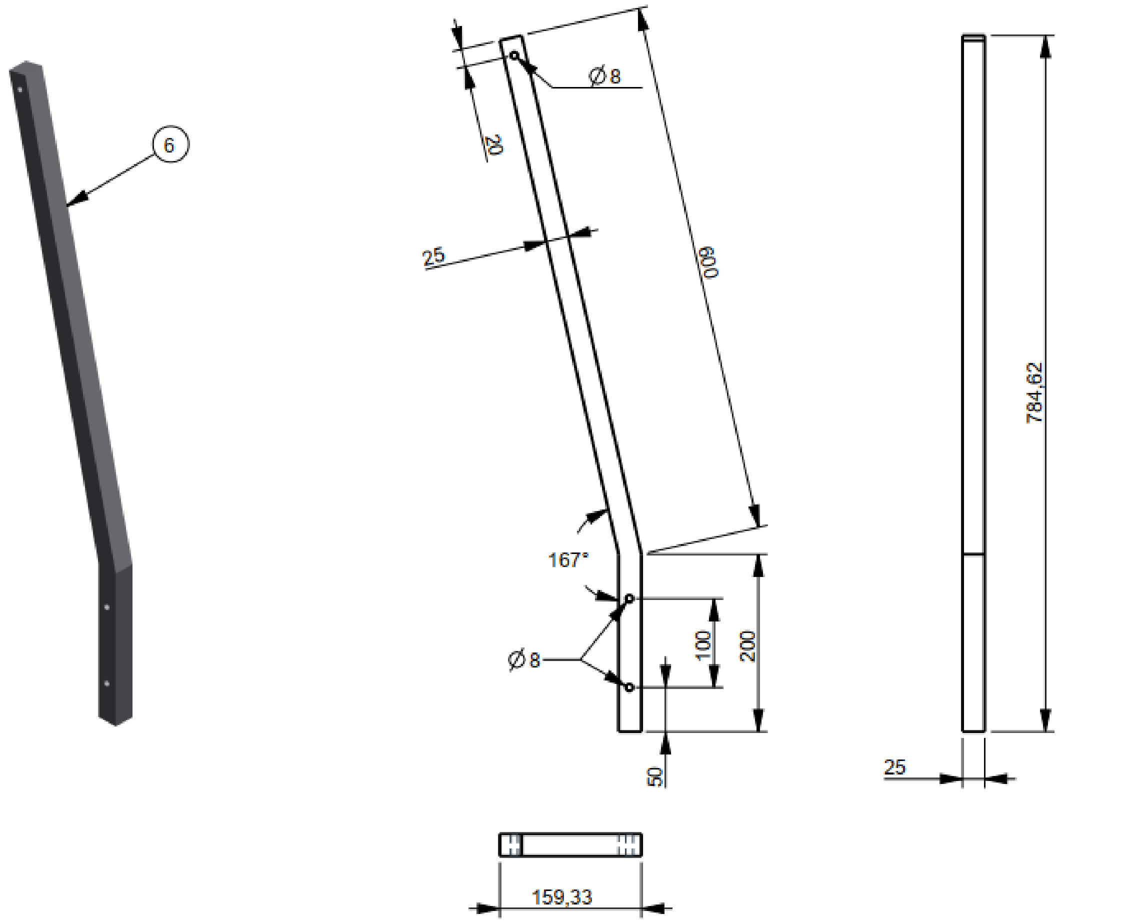
APPENDIX – A.8

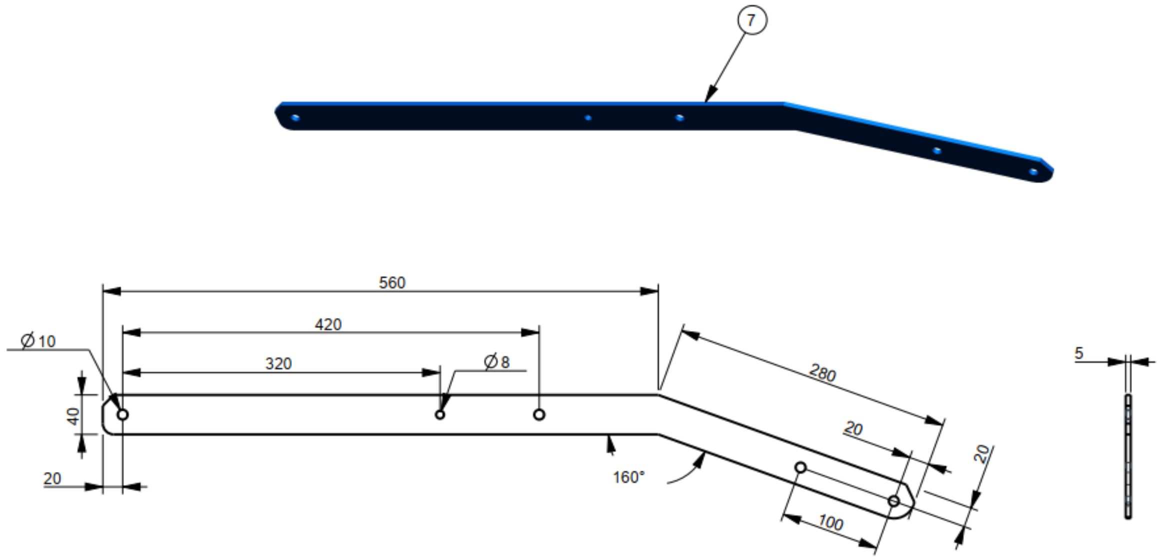
Innovative Cutter for Factory C



APPENDIX – A.8

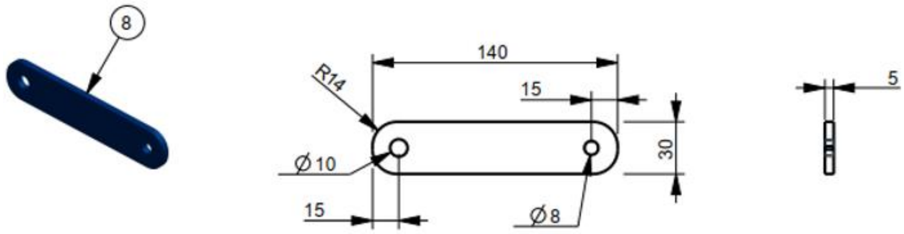
Innovative Cutter for Factory C

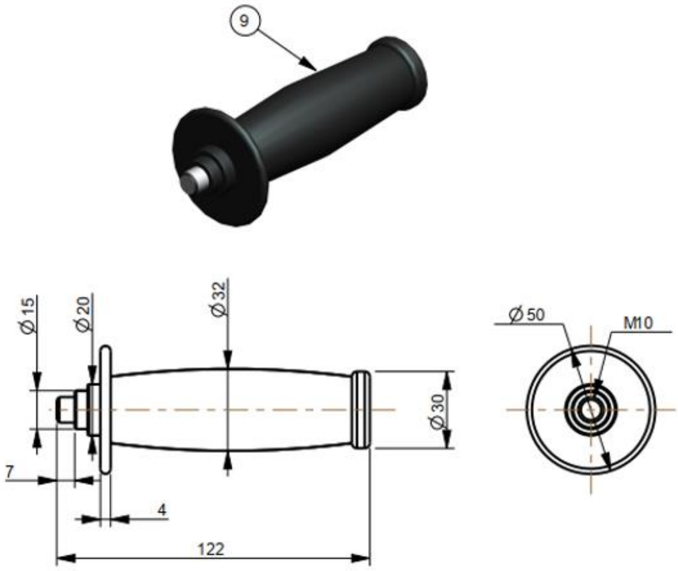


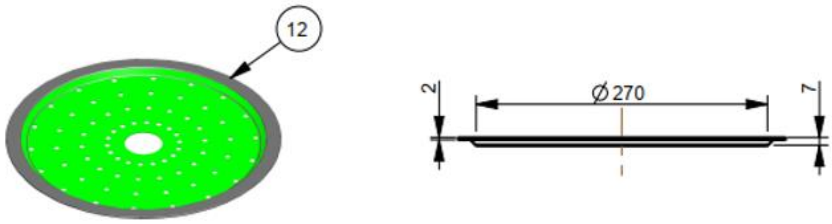


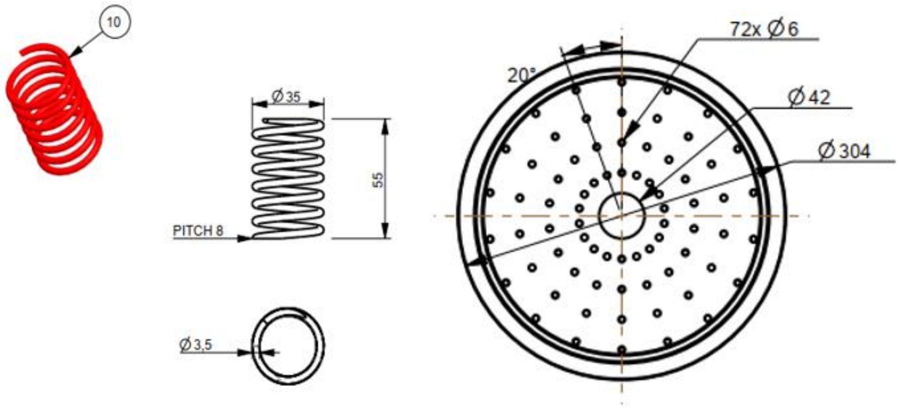
APPENDIX – A.8

Innovative Cutter for Factory C









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2. **Singh, G.**, & Karmakar, S. (2021). Scope of improvement in assembly-line of FMCG industries through ergonomic design. In: *Design for Tomorrow - Volume 3: Proceedings of ICoRD 2021* (pp. 201-214). Springer Singapore. DOI: https://doi.org/10.1007/978-981-16-0084-5_16 **[SCOPUS] [SPRINGER]**

3. **Singh, G.**, & Karmakar, S. (2022). Preliminary survey in FMCG shopfloors to understand operational activities for identifying ergonomic stressors: A case study from North-East India. In: *Ergonomics for Design and Innovation. HWWE 2021*. LNNS. Vol. 391 (93-106). Springer, Cham. DOI: https://doi.org/10.1007/978-3-030-94277-9_9 **[SCOPUS] [SPRINGER]**

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5. **Singh, G**., & Karmakar, S. (2024). Innovative hand-tool design for cleaning of slippery floor and broken glass pieces in shopfloor of FMCG sector. In: *Innovative design for societal needs. NERC 2022*. Springer, Singapore. DOI: https://doi.org/10.1007/978-981-99-6468-0_1 **[SPRINGER]**

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1. **Singh, G**., Karmakar, S., Singh, A., Verma., A., & Chaudhuri, S. (2021). *Hand-held apparatus for extracting contents of sachet/ pouches*. United States (U.S.) Utility Patent No. US 11,319,103. Washington D.C.: USPTO, United States of America (U.S.). **[GRANTED]** https://patentcenter.uspto.gov/applications/17092144

2. **Singh, G**., Singh, A., & Karmakar, S. (2023). *Sachet/ pouch cutting and squeezing apparatus*. Australian Utility Patent Application No. 2022238038. Victoria: AUSPAT. **[ACCEPTED/ To be GRANTED post-completion of 3 months opposition period]** https://ipsearch.ipaustralia.gov.au/patents/2022238038

3. **Singh, G**., Karmakar, S., Singh, A., Verma., A., & Chaudhuri, S. (2020). *Design of safety-enriched sitting-position oriented hand-held apparatus for damaged pouch and sachet cutting for re-work in FMCG industry*. Indian Utility Patent No. 355504. Delhi: IP India. **[GRANTED]** https://iprsearch.ipindia.gov.in/publicsearch

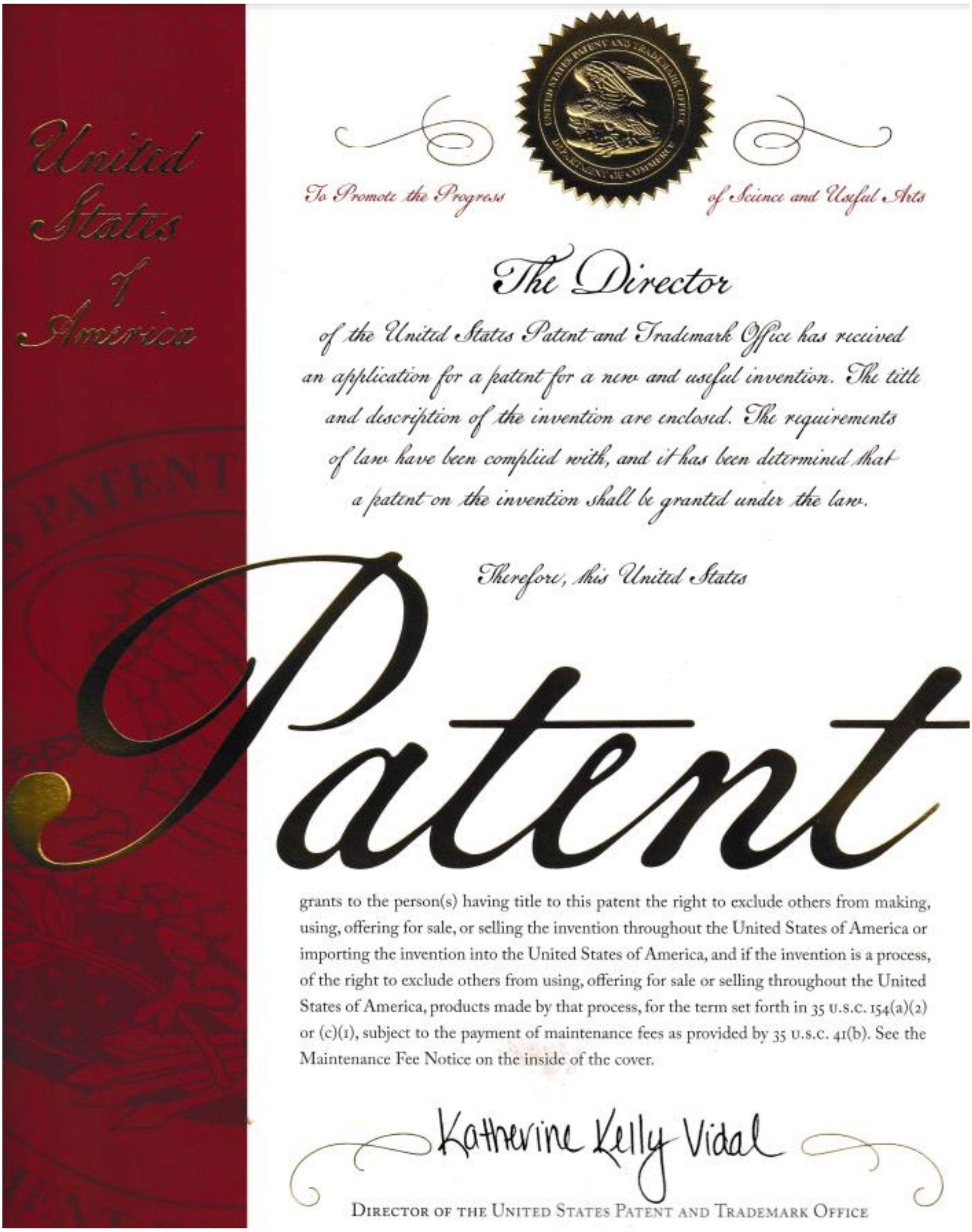
4. **Singh, G**., Karmakar, S., Singh, A., Verma., A., & Chaudhuri, S. (2020). *Design of safety-enriched standing-position oriented mechanized apparatus for damaged pouch and sachet cutting for re-work in FMCG industry*. Indian Utility Patent No. 364959. Delhi: IP India. **[GRANTED]** https://iprsearch.ipindia.gov.in/publicsearch

5. **Singh, G**., Singh, A., & Karmakar, S. (2022). *Pouch/ sachet cutting and squeezing apparatus*. Indian Utility Patent No. 415999. Kolkata: IP India. **[GRANTED]** https://iprsearch.ipindia.gov.in/publicsearch

6. **Singh, G.,** Singh, A., & Karmakar, S. (2022). *Sachet/ pouch cutting and squeezing apparatus*. PCT Application No. PCT/IB2022/056316. Publication No. WO/2022/195572. World Intellectual Property Organization (WIPO), Geneva, Switzerland. **[PUBLISHED]** https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2022195572&_cid=P21-M0UVBZ-74769-1

7. **Singh, G**., Singh, A., & Karmakar, S. (2023). *Sachet/ pouch cutting and squeezing apparatus*. United States (U.S.) Utility Patent Application No. 18/020,030. Washington D.C.: USPTO, United States of America (U.S.). **[UNDER EXAMINATION]** https://patentcenter.uspto.gov/applications/18020030

PATENT CERTIFICATES



United States of America

To Promote the Progress of Science and Useful Arts

The Director

of the United States Patent and Trademark Office has received an application for a patent for a new and useful invention. The title and description of the invention are enclosed. The requirements of law have been complied with, and it has been determined that a patent on the invention shall be granted under the law.

Therefore, this United States

Patent

grants to the person(s) having title to this patent the right to exclude others from making, using, offering for sale, or selling the invention throughout the United States of America or importing the invention into the United States of America, and if the invention is a process, of the right to exclude others from using, offering for sale or selling throughout the United States of America, products made by that process, for the term set forth in 35 U.S.C. 154(a)(2) or (c)(1), subject to the payment of maintenance fees as provided by 35 U.S.C. 41(b). See the Maintenance Fee Notice on the inside of the cover.

Katherine Kelly Vidal

DIRECTOR OF THE UNITED STATES PATENT AND TRADEMARK OFFICE

US011319103B2

(12) **United States Patent**
Singh et al.

(10) **Patent No.: US 11,319,103 B2**
(45) **Date of Patent: May 3, 2022**

(54) **HAND-HELD APPARATUS FOR EXTRACTING CONTENTS OF SACHET/POUCH**

(71) Applicants: **Gurdeep Singh**, Ludhiana (IN); **Sougata Karmakar**, Kamrup (IN); **Abhishek Singh**, Jamshedpur (IN); **Amandeep Verma**, Bijnor (IN); **Sangeeta Bhanja Chaudhuri**, Kolkata (IN)

(72) Inventors: **Gurdeep Singh**, Ludhiana (IN); **Sougata Karmakar**, Kamrup (IN); **Abhishek Singh**, Jamshedpur (IN); **Amandeep Verma**, Bijnor (IN); **Sangeeta Bhanja Chaudhuri**, Kolkata (IN)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **17/092,144**

(22) Filed: **Nov. 6, 2020**

(65) **Prior Publication Data**

US 2021/0292031 A1 Sep. 23, 2021

(51) **Int. Cl.**
B65B 69/00 (2006.01)

(52) **U.S. Cl.**
CPC ***B65B 69/005*** (2013.01); ***B65B 69/0008*** (2013.01); ***B65B 69/0033*** (2013.01)

(58) **Field of Classification Search**
CPC B65B 69/005; B65B 69/0008; B65B 69/0033
USPC 414/412
See application file for complete search history.

(56) **References Cited**

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2021/0094719 A1 * 4/2021 Franke B65B 69/0041

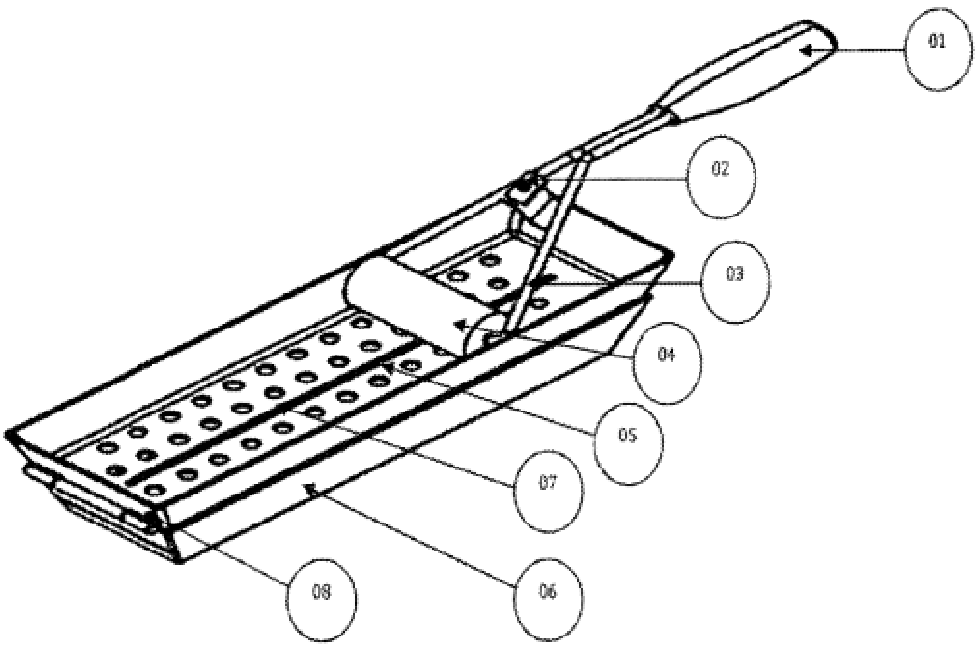
* cited by examiner

Primary Examiner — Glenn F Myers
(74) *Attorney, Agent, or Firm* — Kunzler Bean & Adamson, PC

(57) **ABSTRACT**

A hand-held apparatus for extracting the contents of a sachet/pouch is disclosed. The hand-held apparatus includes a roller press assembly and a roller glider cum collection bin being disposed below the roller press assembly. The roller press assembly further includes a handle, a detachable frame coupled to a handle and a clamp. The detachable frame is provided with a roller for squeezing the contents of a sachet/pouch. The clamp is provided over the detachable frame and the clamp is coupled to a cutter for cutting the sachet/pouch. The roller glider cum collection bin includes a base for receiving the roller press assembly. The base includes a plurality of holes and a guide rail for providing a channel for the cutter. A collection bin is provided at the bottom of the base for collecting the contents of the sachet/pouch through the plurality of holes.

7 Claims, 4 Drawing Sheets



United States (US) Patent Number 11,319,103

Australian Government
IP Australia

8 August 2024

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ABN: 38 113 072 755

Notice of acceptance for your patent application

LexGeneris Pty Ltd
U 2 342 Scarborough Beach Rd
Osborne Park WA 6017
Australia

Application number	2022238038
Applicant name	INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
Your reference	LA/INF/P231008.AU

Dear Applicant,

Your patent application has been examined and was accepted on 2 August 2024. The accepted specification incorporates the following amendments:

S104 amendments up to and including item number: 1

The total number of claims at acceptance has been reported as: 17

What you need to do now

- **Check your details –** attached to this letter are the details of your application at acceptance. Some of these details may be displayed on the Certificate of Grant. Please review your details to ensure that they are correct.

What will happen next

- **An Invitation to Pay (ITP) the acceptance fee will be issued to you** - this fee will include an additional component if the number of claims exceeds 20.
- **Advertisement of acceptance** - a notice of the acceptance will appear in the Australian Official Journal of Patents on 22 August 2024.

Your progress

Filed
Application is filed

Examination
Application is being examined

Acceptance
Application is accepted
(enters an opposition period lasting 3 months)

Grant
Patent is granted
(patent is now enforceable)

Continuation/Renewal
Fees required to maintain application/patent
(fees are due annually – please refer to the 'paid to' date in AusPat for your next due date)

Need help?

Visit our website for more information.

You can also chat with us online from 9am – 5pm.

We're here from Monday to Friday.

If you're outside of these hours, send us a message.

Your acceptance summary

Standard patent details

Patent number:	2022238038
Title:	SACHET/POUCH CUTTING AND SQUEEZING APPARATUS
Your reference:	LA/INF/P231008.AU
Number of claims at acceptance:	17

Applicant and inventor details

Applicant name(s) and address(es) *(as it will appear on certificate/s)* **:**

INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI of Dean II & SI, Office of II & SI, Indian, Institute of Technology Guwahati, North Guwahati, Assam 781039 India

Inventor name(s):	SINGH, Gurdeep SINGH, Abhishek KARMAKAR, Sougata

Agent details

Agent Name	LexGeneris Pty Ltd
Address for correspondence:	U 2 342 Scarborough Beach Rd Osborne Park WA 6017 Australia
Address for legal service:	U 2 342 Scarborough Beach Rd Osborne Park WA 6017 Australia

Prior art details

Prior art documents:
WO 93/24371 A1
CN 104309875 B
CN 113751460 A

Priority details

Number	**Date**	**Country**
202231030090	25 May 2022	IN

International classification

B65D 75/58 (2006.01)
B65B 69/00 (2006.01)

Australian Standard Patent Number 2022238038

INTELLECTUAL PROPERTY INDIA
PATENTS | DESIGNS | TRADE MARKS GEOGRAPHICAL INDICATIONS

सत्यमेव जयते

भारत सरकार
GOVERNMENT OF INDIA

पेटेंट कार्यालय
THE PATENT OFFICE

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PATENT CERTIFICATE
(Rule 74 Of The Patents Rules)

क्रमांक : 011130033
SL No :

पेटेंट सं. / Patent No.	:	355504
आवेदन सं. / Application No.	:	202011011370
फाइल करने की तारीख / Date of Filing	:	17/03/2020
पेटेंटी / Patentee	:	1.MR. GURDEEP SINGH 2.DR. SOUGATA KARMAKAR 3.MR. ABHISHEK SINGH 4.MR. AMANDEEP VERMA et al.

प्रमाणित किया जाता है कि पेटेंटी को उपरोक्त आवेदन में यथाप्रकटित DESIGN OF SAFETY-ENRICHED SITTING-POSITION ORIENTED HAND-HELD APPARATUS FOR DAMAGED POUCH AND SACHET CUTTING FOR RE-WORK IN FMCG INDUSTRIES. नामक आविष्कार के लिए, पेटेंट अधिनियम, १९७० के उपबंधों के अनुसार आज तारीख 17th day of March 2020 से बीस वर्ष की अवधि के लिए पेटेंट अनुदत्त किया गया है।

It is hereby certified that a patent has been granted to the patentee for an invention entitled DESIGN OF SAFETY-ENRICHED SITTING-POSITION ORIENTED HAND-HELD APPARATUS FOR DAMAGED POUCH AND SACHET CUTTING FOR RE-WORK IN FMCG INDUSTRIES. as disclosed in the above mentioned application for the term of 20 years from the 17th day of March 2020 in accordance with the provisions of the Patents Act,1970.

पेटेंट कार्यालय THE PATENT OFFICE GOVT.OF INDIA भारत सरकार

अनुदान की तारीख : 08/01/2021
Date of Grant :

पेटेंट नियंत्रक
Controller of Patent

टिप्पणी - इस पेटेंट के नवीकरण के लिए फीस, यदि इसे बनाए रखा जाना है, **17th day of March 2022** को और उसके पश्चात प्रत्येक वर्ष में उसी दिन देय होगी।

Note. - The fees for renewal of this patent, if it is to be maintained will fall / has fallen due on 17th day of March 2022 and on the same day in every year thereafter.

Indian Patent Number 355504

INTELLECTUAL
PROPERTY **INDIA**
PATENTS | DESIGNS | TRADE MARKS
GEOGRAPHICAL INDICATIONS

सत्यमेव जयते

क्रमांक : 011133676
SL No :

भारत सरकार
GOVERNMENT OF INDIA
पेटेंट कार्यालय
THE PATENT OFFICE
पेटेंट प्रमाणपत्र
PATENT CERTIFICATE
(Rule 74 Of The Patents Rules)

पेटेंट सं. / Patent No.	:	364959
आवेदन सं. / Application No.	:	202011011369
फाइल करने की तारीख / Date of Filing	:	17/03/2020
पेटेंटी / Patentee	:	1.MR. GURDEEP SINGH 2.DR. SOUGATA KARMAKAR 3.MR. ABHISHEK SINGH 4.MR. AMANDEEP VERMA et al.

प्रमाणित किया जाता है कि पेटेंटी को उपरोक्त आवेदन में यथाप्रकटित DESIGN OF SAFETY-ENRICHED STANDING-POSITION ORIENTED MECHANIZED APPARATUS FOR DAMAGED POUCH AND SACHET CUTTING FOR RE-WORK IN FMCG INDUSTRIES. नामक आविष्कार के लिए, पेटेंट अधिनियम, १९७० के उपबंधों के अनुसार आज तारीख 17th day of March 2020 से बीस वर्ष की अवधि के लिए पेटेंट अनुदत्त किया गया है।

It is hereby certified that a patent has been granted to the patentee for an invention entitled DESIGN OF SAFETY-ENRICHED STANDING-POSITION ORIENTED MECHANIZED APPARATUS FOR DAMAGED POUCH AND SACHET CUTTING FOR RE-WORK IN FMCG INDUSTRIES. as disclosed in the above mentioned application for the term of 20 years from the 17th day of March 2020 in accordance with the provisions of the Patents Act,1970.

THE PATENT OFFICE
GOVT.OF INDIA

अनुदान की तारीख : 20/04/2021
Date of Grant :

पेटेंट नियंत्रक
Controller of Patent

टिप्पणी - इस पेटेंट के नवीकरण के लिए फीस, यदि इसे बनाए रखा जाना है, **17th day of March 2022** को और उसके पश्चात प्रत्येक वर्ष मे उसी दिन देय होगी।

Note. - The fees for renewal of this patent, if it is to be maintained will fall / has fallen due on 17th day of March 2022 and on the same day in every year thereafter.

Indian Patent Number 364959

INTELLECTUAL PROPERTY INDIA
PATENTS | DESIGNS | TRADE MARKS
GEOGRAPHICAL INDICATIONS

सत्यमेव जयते

क्रमांक : 033122540
SL No :

भारत सरकार
GOVERNMENT OF INDIA
पेटेंट कार्यालय
THE PATENT OFFICE
पेटेंट प्रमाणपत्र
PATENT CERTIFICATE
(Rule 74 of The Patents Rules)

पेटेंट सं. / Patent No.	:	415999
आवेदन सं. / Application No.	:	202231030090
फाइल करने की तारीख / Date of Filing	:	25/05/2022
पेटेंटी / Patentee	:	Indian Institute of Technology Guwahati
आविष्कारक (जहां लागू हो) / Inventor(s)	:	1.SINGH, Gurdeep 2.SINGH, Abhishek 3.KARMAKAR, Sougata

प्रमाणित किया जाता है कि पेटेंटी को, उपरोक्त आवेदन में यथाप्रकटित SACHET/POUCH CUTTING AND SQUEEZING APPARATUS नामक आविष्कार के लिए, पेटेंट अधिनियम, 1970 के उपबंधों के अनुसार आज तारीख मई 2022 के पच्चीसवें दिन से बीस वर्ष की अवधि के लिए पेटेंट अनुदत्त किया गया है।

It is hereby certified that a patent has been granted to the patentee for an invention entitled SACHET/POUCH CUTTING AND SQUEEZING APPARATUS as disclosed in the above mentioned application for the term of 20 years from the 25th day of May 2022 in accordance with the provisions of the Patents Act,1970.

THE PATENT OFFICE
GOVT.OF INDIA

अनुदान की तारीख : 29/12/2022
Date of Grant :

पेटेंट नियंत्रक
Controller of Patent

टिप्पणी - इस पेटेंट के नवीकरण के लिए फीस, यदि इसे बनाए रखा जाना है, मई 2024 के पच्चीसवें दिन को और उसके पश्चात प्रत्येक वर्ष में उसी दिन देय होगी।

Note. - The fees for renewal of this patent, if it is to be maintained will fall / has fallen due on 25th day of May 2024 and on the same day in every year thereafter.

Indian Patent Number 415999

LIST OF DESIGN REGISTRATIONS

1. **Singh, G**., Karmakar, S., Verma., A., & Singh, A. (2020). *Mechanized Pouch Cutter*. Indian Design No. 329288-001 in Class: 08-03. Kolkata: IP India. **[GRANTED]** https://designdb.wipo.int/designdb/en/

2. **Singh, G**., Karmakar, S., Verma., A., & Singh, A. (2020). *Ergonomic Sachet Cutting Apparatus for FMCG Re-work*. Indian Design No. 329290-001 in Class: 08-03. Kolkata: IP India. **[GRANTED]** https://designdb.wipo.int/designdb/en/

3. **Singh, G**., Singh, A., & Karmakar, S. (2022). *Cutting and Squeezing Apparatus for Defective Pouch/ Sachet Rework*. Indian Design No. 360578-001 in Class: 08-03. Kolkata: IP India. **[GRANTED]** https://designdb.wipo.int/designdb/en/

4. **Singh, G**., & Karmakar, S. (2022). *Ergonomic Housekeeping Device for FMCG Industries*. Indian Design No. 372750-001 in Class: 15-05. Kolkata: IP India. **[GRANTED]** https://designdb.wipo.int/designdb/en/

DESIGN CERTIFICATES

THE PATENT OFFICE KOLKATA - 700 091

सत्यमेव जयते

ORIGINAL

No. 88900

भारत सरकार
GOVERNMENT OF INDIA
पेटेंट कार्यालय
THE PATENT OFFICE

CERTIFICATE OF REGISTRATION OF DESIGN

Design No.	329288-001
Date	12/05/2020 22:59:13
Reciprocity Date*	
Country	

Certified that the design of which a copy is annexed hereto has been registered as of the number and date given above in class 08-03 in respect of the application of such design to MECHANIZED POUCH CUTTER FOR FMCG RE-WORK in the name of 1.GURDEEP SINGH, PH.D. ENCLAVE, DEPARTMENT OF DESIGN, IIT GUWAHATI, ASSAM. 2. SOUGATA KARMAKAR, ASSOCIATE PROFESSOR, DEPARTMENT OF DESIGN, IIT GUWAHATI. 3. AMANDEEP VERMA, DEPARTMENT OF DESIGN, IIT GUWAHATI. 4. ABHISHEK SINGH, PH.D. ENCLAVE, DEPARTMENT OF DESIGN.

in pursuance of and subject to the provisions of the Designs Act, 2000 and the Designs Rules, 2001.

INTELLECTUAL PROPERTY INDIA PATENTS | DESIGNS | TRADE MARKS GEOGRAPHICAL INDICATIONS

Controller General of Patents, Designs and Trade Marks

*The reciprocity date (if any) which has been allowed and the name of the country.
Copyright in the design will subsist for ten years from the date of Registration, and may underthe terms of the Act and Rules, be extended for a further period of five years.
This Certificate is not for use in legal proceedings or for obtaining registration abroad

MR. GURDEEP SINGH,
PH.D. ENCLAVE, DEPARTMENT OF DESIGN, IIT GUWAHATI, DISTT: KAMRUP, ASSAM, PIN: 781039

Date of Issue 01/07/2020 16:10:00

Indian Design Number 329288-001

ORIGINAL

No. **96104**

THE PATENT OFFICE KOLKATA - 700 091

सत्यमेव जयते

भारत सरकार

GOVERNMENT OF INDIA

पेटेंट कार्यालय

THE PATENT OFFICE

CERTIFICATE OF REGISTRATION OF DESIGN

Design No.	329290-001
Date	13/05/2020 01:17:18
Reciprocity Date*	
Country	

Certified that the design of which a copy is annexed hereto has been registered as of the number and date given above in class 08-03 in respect of the application of such design to ERGONOMIC SACHET CUTTING APPARATUS FOR FMCG RE-WORK in the name of 1.GURDEEP SINGH, NEW MARRIED SCHOLAR QUARTER NO. 307, IIT GUWAHATI CAMPUS, NORTH GUWAHATI, DISTT: KAMRUP, PIN: 781039 2. SOUGATA KARMAKAR, ASSOCIATE PROFESSOR, DEPARTMENT OF DESIGN, IIT GUWAHATI 3. AMANDEEP VERMA, DEPARTMENT OF DESIGN, IIT GUWAHATI 4. ABHISHEK SINGH, OLD MARRIED SCHOLAR QUARTER NO. 28, IIT GUWAHATI CAMPUS

in pursuance of and subject to the provisions of the Designs Act, 2000 and the Designs Rules, 2001.

Controller General of Patents, Designs and Trade Marks

*The reciprocity date (if any) which has been allowed and the name of the country.
Copyright in the design will subsist for ten years from the date of Registration, and may underthe terms of the Act and Rules, be extended for a further period of five years.
This Certificate is not for use in legal proceedings or for obtaining registration abroad

MR. GURDEEP SINGH,
NEW MARRIED SCHOLAR QUARTER NO. 307, IIT GUWAHATI CAMPUS, NORTH GUWAHATI, DISTT: KAMRUP, ASSAM, PIN: 781039

Date of Issue 26/02/2021 15:04:34

Indian Design Number 329290-001

ORIGINAL

No. 113993

सत्यमेव जयते

भारत सरकार
GOVERNMENT OF INDIA
पेटेंट कार्यालय
THE PATENT OFFICE

CERTIFICATE OF REGISTRATION OF DESIGN

Design No.	360578-001
Date	14/03/2022 15:36:48
Reciprocity Date*	
Country	

Certified that the design of which a copy is annexed hereto has been registered as of the number and date given above in class 08-03 in respect of the application of such design to CUTTING AND SQUEEZING APPARATUS FOR DEFECTIVE POUCH/ SACHET REWORK in the name of 1.INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI, OFFICE OF DEAN, II & SI, IIT GUWAHATI, PIN: 781039 2. GURDEEP SINGH, ERGONOMICS LABORATORY, DESIGN DEPARTMENT, IIT GUWAHATI, PIN: 781039 3. ABHISHEK SINGH, PH.D. ENCLAVE, DESIGN DEPARTMENT, IIT GUWAHATI, PIN: 781039 4. SOUGATA KARMAKAR, ASSOCIATE PROFESSOR, DEPTT. OF DESIGN, IIT GUWAHATI, PIN: 781039

in pursuance of and subject to the provisions of the Designs Act, 2000 and the Designs Rules, 2001.

Controller General of Patents, Designs and Trade Marks

*The reciprocity date (if any) which has been allowed and the name of the country.
Copyright in the design will subsist for ten years from the date of Registration, and may underthe terms of the Act and Rules, be extended for a further period of five years.
This Certificate is not for use in legal proceedings or for obtaining registration abroad.

DR. SOUGATA KARMAKAR,
ASSOCIATE PROFESSOR, DEPARTMENT OF DESIGN,
IIT GUWAHATI, NORTH GUWAHATI, ASSAM. PIN:
781039

Date of Issue 23/05/2022 12:54:12

Indian Design Number 360578-001

INTELLECTUAL PROPERTY INDIA
PATENTS | DESIGNS | TRADE MARKS
GEOGRAPHICAL INDICATIONS

सत्यमेव जयते

ORIGINAL
क्रम सं/ Serial No. : 151057

पेटेंट कार्यालय, भारत सरकार The Patent Office, Government Of India

डिजाइन के पंजीकरण का प्रमाण पत्र | Certificate of Registration of Design

डिजाइन सं. / Design No. : 372750-001

तारीख / Date : 18/10/2022

पारस्परिकता तारीख / Reciprocity Date* :

देश / Country :

प्रमाणित किया जाता है कि संलग्न प्रति में वर्णित डिजाइन जो *ERGONOMIC HOUSEKEEPING DEVICE FOR FMCG INDUSTRIES* से संबंधित है, का पंजीकरण, श्रेणी 15-05 में 1.Indian Institute Of Technology Guwahati 2. Gurdeep Singh 3.Sougata Karmakar के नाम में उपर्युक्त संख्या और तारीख में कर लिया गया है।

Certified that the design of which a copy is annexed hereto has been registered as of the number and date given above in class 15-05 in respect of the application of such design to *ERGONOMIC HOUSEKEEPING DEVICE FOR FMCG INDUSTRIES* in the name of 1.Indian Institute Of Technology Guwahati 2. Gurdeep Singh 3.Sougata Karmakar.

डिजाइन अधिनियम, 2000 तथा डिजाइन नियम, 2001 के अध्यधीन प्रावधानों के अनुसरण में।
In pursuance of and subject to the provisions of the Designs Act, 2000 and the Designs Rules, 2001.

जारी करने की तिथि : 27/12/2023
Date of Issue

महानियंत्रक पेटेंट, डिजाइन और व्यापार चिह्न
Controller General of Patents, Designs and Trade Marks

*पारस्परिकता तारीख (यदि कोई हो) जिसकी अनुमति दी गई है तथा देश का नाम। डिजाइन का स्वत्वाधिकार पंजीकरण की तारीख से दस वर्षों के लिए होगा जिसका विस्तार, अधिनियम एवं नियम के निबंधनों के अधीन, पाँच वर्षों की अतिरिक्त अवधि के लिए किया जा सकेगा। इस प्रमाण पत्र का उपयोग विधिक कार्यवाहियों अथवा विदेश में पंजीकरण प्राप्त करने के लिए नहीं हो सकता है।

The reciprocity date (if any) which has been allowed and the name of the country. Copyright in the design will subsist for ten years from the date of Registration, and may under the terms of the Act and Rules, be extended for a further period of five years. This Certificate is not for use in legal proceedings or for obtaining registration abroad.

Indian Design Number 372750-001

LIST OF AWARDS

1. **Alexander C. Williams, Jr., Design Award 2023**, awarded by the Human Factors and Ergonomics Society (HFES), Washington D.C., U.S. (23rd October 2023 at Hotel Washington Hilton, Washington D.C., U.S.) Link: https://shorturl.at/nqDIR and https://shorturl.at/YSZ2E

2. **International Ergonomics Association's Kingfar (IEA Kingfar) Award 2021 (1,000 USD),** awarded by IEA, Geneva, Switzerland (award conferred at IEA 2024, 22nd Triennial Congress of IEA, scheduled 25-29th August 2024, Jeju Islands, South Korea). Link: https://iea.cc/awards/iea-kingfar-award

3. **The Innovation Award 2023 *(Runner-up) (10,000 USD)***, awarded at the PREMUS, WDPI, and MYOPAIN 2023, ICoH and IEA endorsed International Scientific Conference, Bengaluru, India. (23-26th September 2023, St. John's Medical College, Bengaluru, Karnataka, India). Link: https://shorturl.at/cquM6

4. **The Innovation Award 2022 (Highly Commended Innovation)**, awarded by the Chartered Institute of Ergonomics & Human Factors (CIEHF), United Kingdom (U.K.). https://shorturl.at/YmMmP

5. **The Gandhian Young Technological Innovation (GYTI) Award 2023 (Appreciation),** awarded by SRISTI, GIAN & Honey Bee Network, Ahmedabad, Gujarat, India. Link: https://shorturl.at/phlfU

6. **The Dieter W. Jahns Student Practitioner Award 2024 (Runner-up),** awarded by the Foundation for Professional Ergonomics (FPE), Bellingham, Washington, United States (U.S.). Link: https://shorturl.at/osYig

7. **The Don Norman Design Award (DNDA) 2024 (Finalist),** The Don Norman (DN) Charity Organization, United States (U.S.). Link: https://shorturl.at/lXycx

AWARD CERTIFICATES/ LETTERS

September 21, 2023

Gurdeep Singh
Indian Institute of Technology (IIT) Guwahati
New Married Scholar Quarter No. 307,
IIT Guwahati Campus, North Guwahati
District Kamrup, Assam
Guwahati, Assam 781039

HFES
Systems That Work for Humans

Dear Mr. Singh:

As president of the Human Factors and Ergonomics Society, I am very pleased to inform you that you are the recipient of the Human Factors and Ergonomics Society's **2023 Alexander C. Williams, Jr. Design Award**. This award is presented in recognition of outstanding contributions to the conception or design of a product, service, or system that has had a significant impact on users and exemplifies the excellent use of empirical human factors/ergonomics design principles.

The award is given following a very careful review of your distinguished accomplishments, as submitted in application packet. The Alexander C. Williams, Jr., Design Award Committee reviewed the nomination, chaired by Neal Wiggerman. Subsequently it was reviewed and approved by the Executive Council of the Human Factors and Ergonomics Society.

The award will be presented on Monday, October 23, 2023, at an evening reception and awards ceremony at the Washington Hiltons Hotel. You are cordially invited to this session to receive your award in person. We will provide additional details concerning logistics in a follow-up email. Kindly RSVP to Joann DeNardis, Sr. Operations Manager, at jdenardis@hfes.org by ***Friday, August 25*** to indicate whether you will be able to join us in Washington, DC at the awards ceremony.

Congratulations, Dr. Singh, and, on behalf of the Society, many thanks for your important contributions. We are pleased to add your name to the roster of outstanding recipients of Alexander C. Williams, Jr., Design Award.

Sincerely,

Carolyn Sommerich, Ph.D., CPE, FHFES
President

cc:
Sougata Karmakar
Neal Wiggerman
Ronald Boring, Ph.D.
Joann DeNardis

HUMAN FACTORS AND ERGONOMICS SOCIETY
2001 K STREET NW, 3RD FLOOR NORTH | WASHINGTON, DC 20006
TEL. + 1 (202) 367-1114 | INFO@HFES.ORG

Alexander C. Williams Jr. Design Award 2023, HFES, United States of America

Past President and Awards Chair
Dr. Kathleen L. Mosier
Human Factors and Ergonomics Society
Emeritus Professor, Psychology Department
San Francisco State University
San Francisco, CA 94132, USA
kmosier@sfsu.edu

International Ergonomics Association

15 December, 2021

Dear Gurdeep Singh,

Congratulations! On behalf of the IEA Executive Committee, I am delighted to inform you that you have been selected to receive the IEA/Kingfar Award. This award is given annually in recognition of outstanding Student Research in Human Factors / Ergonomics Issues in Industrially Developing Countries. The purpose of the IEA/Kingfar Award is to encourage excellent students to explore original research and applications on HFE issues typical of IDCs, thereby contributing to the wellbeing of people in these countries. The reviewers of your application agreed that you and your work are highly deserving of the IEA/Kingfar award.

The monetary award of $1000USD will be transferred by IEA to your bank account. Please complete the attached fund transfer form and send it back to me.

A list of previous recipients can be found at
https://iea.cc/annual-awards/iea-kingfar-award/

We hope you will be able to join us at the next IEA Congress, IEA2024, in Jeju, Korea so we can give personal and public recognition for your achievement.

Thank you for your superior contributions to the discipline of human factors / ergonomics and, again, congratulations on this well-deserved recognition. We hope it will mark the beginning of an excellent and productive career in human factors/ergonomics.

If you have any questions or if I can assist in any way, please do not hesitate to contact me at kmosier@sfsu.edu.

Warm regards,

Kathleen L. Mosier, PhD.
Kathleen Mosier
Past President & Awards Chair
International Ergonomics Association

Jose Orlando Gomes
President
International Ergonomics Association

The IEA is registered as an association at the Commercial Registry of the Canton of Geneva, Switzerland:
Company-Nr. CHE-114.873.584.

IEA Kingfar Award 2021, Geneva, Switzerland

CERTIFICATE OF EXCELLENCE

Proudly Presented To:

GURDEEP SINGH - ERGONOMICS LAB, IIT GUWAHATI

As

Runner Up - Innovation Awards

At the

PREMUS, WDPI, & MYOPAIN 2023 International Scientific Conference

In recognition of your outstanding contribution, groundbreaking innovation and commitment to improving Musculoskeletal Health and Work Disabilities Prevention, we proudly present this Certificate of Excellence and a cash prize of **$10,000**.

September 20th-26th, 2023 | Bengaluru, India

Deepak Sharan

Dr Deepak Sharan
Organising Chairperson

nasscom Center of Excellence-IoT & AI

WDPI & PREMUS 2023

CONFERENCE HOST & SPONSOR recoup HEALTH

The Innovation Award 2023 (PREMUS), Bengaluru, India

Chartered Institute
of Ergonomics
& Human Factors

CERTIFICATE

This is to certify that

Gurdeep Singh

has been **highly commended** for the

INNOVATION AWARD 2022

of the Chartered Institute of Ergonomics & Human Factors for outstanding and innovative contributions to ergonomics and human factors.

Chris Ramsden Chair of the Honours Committee	Richard Graveling Registrar

Chartered Institute
of Ergonomics
& Human Factors

Well done!

With compliments

t: 07736 893350
e: ciehf@ergonomics.org.uk
w: www.ergonomics.org.uk

Tina

The Innovation Award 2022 (CIEHF), United Kingdom

Gmail

Gurdeep Singh <phdgur@gmail.com>

Selection of Proposal for GYTI-2023 Appreciation

GYTI Techpedia <gyti.techpedia@sristi.org>
To: Gurdeep Singh <phdgur@gmail.com>

1 October 2024 at 11:01

Dear Gurdeep

Greetings of the day!

I am immensely pleased to announce that your proposal number 16312 entitled **"Safety-enriched pouch/sachet cutter for FMCG rework"** has been selected for the GYTI-2023 appreciation. The details of the award ceremony will be updated soon. I congratulate you and your team members on your success.

--

Dr. Swasti Dhagat

Coordinator, GYTI awards
Team Techpedia
Society for Research and Initiatives for Sustainable Technologies and Institutions (SRISTI) ***- A developmental voluntary organization***
AES Boys' Hostel Campus, Navrangpura, Ahmedabad, Gujarat (IND) - 380009
www.sristi.org | *www.techpedia.in* | *www.gyti.techpedia.in*
Mob: *(+91) 9099258492* | ***Tel:*** *(+91) 079 - 27912792, 27913293*

The Gandhian Young Technological Innovation (GYTI) Award 2023, SRISTI, India

FOUNDATION FOR
Professional Ergonomics

Certificate of Appreciation

Is Hereby Presented To

Gurdeep Singh

In Recognition of the Project *"Design and Development of Safety-enriched Innovative Tools for Pouch/ Sachet Cutting in FMCG Rework Activities"*

Runner-up for the 2024 Dieter W. Jahns Student Practitioner Award

August 12, 2024

Robert J. Smillie, PhD, C.ErgHF, CPE
President
Foundation for Professional Ergonomics

The Dieter W. Jahns Student Practitioner Award 2024 (FPE), United States of America

Gmail **Gurdeep Singh <phdgur@gmail.com>**

Congratulations on reaching the FINALIST stage of DNDA

DNDA Staff <info@dnda.design> 4 August 2024 at 23:04
Cc: info@dnda.design
Bcc: phdgur@gmail.com

Don Norman
Design Award

The DNDA judges have completed their reviews of applications.

We are pleased to tell you that your entry was a FINALIST. Congratulations, your entry is among the very few of the many applications that we received to have this honor.

Although in the end, your project was not selected for an award, the judges all agreed that your project was excellent. Your work stood out among the many other excellent applications that we received.

You may post an announcement on your social media channels that your application was a FINALIST for an award. When we publicize your recognition, please help us by telling us the account names of the social media that you use so that we can refer to your account.

If you can attend the Summit on November 14-15 in San Diego, California, USA, you will be among many other people working on projects of societal value, including a number of successful organizations who will share their learnings. This is a good place for networking, and for learning.

Thank you for your excellent submission.

Anil Kripalani
CEO, The Don Norman Design Award Charity

Don Norman

The Don Norman Design Award (DNDA) 2024, United States of America