DESIGN AND DEVELOPMENT OF CELL TO CELL CONVEYOR SYSTEM

This report is submitted in accordance with requirement of the Universiti Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

By

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I hereby, declared this report entitled “Design abd development of cell to cell conveyor system” is the result of my own research expect as cited in references.

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APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Engineering Materials) (Hons). The member of the supervisory committee are as follow:

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DEDICATION

The sake of Allah, my Creator and my Master,

My great teacher and messenger, Muhammad (May Allah bless and grant him), who taught us the purpose of life,

My great parents, who never stop giving of themselves in countless ways, who leads me through the valley of darkness with light of hope and support,

My beloved brother and sister,

To all my family, the symbol of love and giving,

My friends who encourage and support me,

All the people in my life who touch my heart, I dedicate this research.

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ABSTRACT

The conceptualization and development of a cell to cell conveyor system is a breakthrough in the field of material handling and manufacturing automation. This innovative system diverges from conventional conveyors by enhancing the smooth delivery of goods across various angles, thereby optimizing spatial efficiency and promoting agility within manufacturing processes. Unlike traditional conveyors that may exhibit limitations in accommodating multidirectional movement, this system facilitates seamless maneuverability, ensuring efficient utilization of available space and enhancing operational flexibility. The design and advancement of cell to cell conveyor systems necessitate meticulous consideration of various specific requirements. Key factors include the layout configuration of the conveyor system, the choice between wheels or rollers, the selection of mechanical belts suitable for product characteristics, seamless integration with pre-existing infrastructure, and the optimization of performance parameters to align with operational needs, particularly in facilitating the delivery of goods at varying elevations. The project involved a comprehensive approach, starting from the initial design requirements for the cell-to-cell delivery system to the actual development and subsequent evaluation of its functionality and usability. An important aspect of the project required the use of a 3D modeling application such as Catia V5 to produce a detailed representation of the conveyor system. Furthermore, the incorporation of additive manufacturing techniques is essential to create cell to cell specific transmitters, ensuring tailored and efficient solutions. The final prototype underwent load test, current test, rpm test and angle test throughout the operation. The results show that prototype design should prioritize performance and efficiency, flexibility and adaptability. Load analysis reveals the maximum load capacity for the conveyor system is 128.33 N. The load test and angle test shows changes in rpm and current where the gap is 246 rpm to 155 rpm (36.86% decrease) and 2.36 A to 4.8 A (103.4% increase). The prototype of the cell to cell conveyor system has yielded favorable outcomes in terms of its efficacy and usability for transporting goods, thereby enhancing efficiency within the logistics industry.

ABSTRAK

Konseptualisasi dan pembangunan sistem penghantar sel ke sel merupakan satu kejayaan dalam bidang pengendalian bahan dan automasi pembuatan. Sistem inovatif ini menyimpang daripada penghantar konvensional dengan meningkatkan kelancaran penghantaran barangan merentasi pelbagai sudut, dengan itu mengoptimumkan kecekapan spatial dan menggalakkan ketangkasan dalam proses pembuatan. Tidak seperti penghantar tradisional yang mungkin mempamerkan batasan dalam menampung pergerakan pelbagai arah, sistem ini memudahkan kebolehgerakan yang lancar, memastikan penggunaan ruang yang ada dengan cekap dan meningkatkan fleksibiliti operasi. Reka bentuk dan kemajuan sistem penghantar sel ke sel memerlukan pertimbangan yang teliti terhadap pelbagai keperluan khusus. Faktor utama termasuk konfigurasi susun atur sistem penghantar, pilihan antara roda atau penggelek, pemilihan tali pinggang mekanikal yang sesuai untuk ciri-ciri produk, penyepaduan lancar dengan infrastruktur sedia ada, dan pengoptimuman parameter prestasi agar sejajar dengan keperluan operasi, terutamanya dalam memudahkan penghantaran barang pada ketinggian yang berbeza-beza. Projek ini melibatkan pendekatan yang komprehensif, bermula daripada keperluan reka bentuk awal untuk sistem penghantaran sel ke sel kepada pembangunan sebenar dan penilaian seterusnya kefungsian dan kebolehgunaannya. Aspek penting projek memerlukan penggunaan aplikasi pemodelan 3D seperti Catia V5 untuk menghasilkan perwakilan terperinci sistem penghantar. Tambahan pula, penggabungan teknik pembuatan aditif adalah penting untuk mencipta pemancar khusus sel ke sel, memastikan penyelesaian yang disesuaikan dan cekap. Prototaip akhir menjalani ujian beban, ujian semasa, ujian rpm dan ujian sudut sepanjang operasi. Keputusan menunjukkan bahawa reka bentuk prototaip harus mengutamakan prestasi dan kecekapan, fleksibiliti dan kebolehsuaian. Analisis beban mendedahkan kapasiti beban maksimum untuk sistem penghantar ialah 128.33 N. Ujian beban dan ujian sudut menunjukkan perubahan dalam rpm dan arus di mana jurang adalah 246 rpm hingga 155 rpm (penurunan 36.86%) dan 2.36 A hingga 4.8 A (103.4% meningkat). Prototaip sistem penghantar sel ke sel telah menghasilkan hasil yang menggalakkan dari segi keberkesanan dan kebolehgunaannya untuk mengangkut barangan, sekali gus meningkatkan kecekapan dalam industri logistik.

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CHAPTER 1

INTRODUCTION

This chapter introduces the project and briefly discuss the project background problem statement, objective and also the scopes.

1.1 Project background

A conveyor system is a common piece of mechanical handling equipment that moves materials from one location to another. Conveyors are especially useful in applications involving the transportation of heavy or bulky materials. Conveyor systems allow quick and efficient transportation for a wide variety of materials, which make them very popular in the material handling and packaging industries (Alspaugh M.A, 2004). Conveyor systems can be used to move parts between automation systems and also within a single automation system. Conveyors provide for fixed movement between two points along a predetermined path. They can be on the floor, located above the floor or positioned overhead. The selection depends on the product to be moved, the space available, and the access required to the other equipment and operations. They are particularly suited to moving high volumes of product and can also provide temporary storage or buffers between specific operations (Wilson, 2015).

Various types of conveyor are used to move bulk solids as well as packaged materials. These may be broadly classified into belt, pneumatic, vibratory, worm (or screw), en masse (or drag link), and bucket types (Moran, 2017). Belt conveyors have a certain minimum distance at which they can be located from the units due to the maximum angle of slope of the conveyor, generally inclined to angles up to 20 degrees and declined to 15 degrees. Usually, fine granular materials can be conveyed at steeper angles than coarse or lumpy materials and runback of material is minimized if belts are slow running and heavily laden. The Figure 1.1 shows the belt conveyor.

Figure 1.1 The belt conveyor (Source: H.S engineering Noido, 2017)

These are suitable for powders or granular materials which are within a reasonably close size range, and will not suffer from attrition or moisture pickup. Pneumatic conveyor pipework can be routed at any angle, but long sweep bends are sometimes necessary to avoid blockage and wear. The system is generally purged with clean air after use to avoid settlement. The air supply should be clean and dry, and conveying air must be separated from the conveyed material at the discharge point. The Figure 1.2 shows the pneumatic conveyor.

Figure 1.2 The pneumatic conveyor (Source: Report, 2019)

Care must be taken in vibratory conveyor design and layout to avoid transmission of vibration to surrounding plant and structures, unless it is desirable to aid flow from feed hoppers. It should be noted that there may be negative implications for flow channel development if such an approach is taken. Material feed and discharge can be positioned anywhere along the length of the conveyor. Solids of different size ranges to be handled by a common conveyor are best brought to one common feed point to avoid choking, as could occur if a slow moving stream is fed in ahead of another faster moving one. The figure 1.3 shows the vibratory conveyor.

Figure 1.3 The vibratory conveyor (Source: Bakers journel, 2020)

The blockages which can occur on worm (screw) conveyor internal hanger bearings when handling sticky materials can be avoided if sufficient height is available, by covering the required distance with a series of short conveyors which do not need internal hanger bearings or shaft supports. The Figure 1.4 shows the worm conveyor.

Figure 1.4 The worm conveyor (Source: Promid transportna tehnika, 2020)

The findings of this study will surely assist industrial workers in taking suitable action to conveyor cell to cell that meets the the conveyor's dimensions are up to code for all sectors. Looking for a solution Guaranteeing the development of smart industry-relevant technologies and make sure no foreign items can become lodged in the conveyor system by constructing appropriate conveyors that prevent this from happening.

1.2 Problem statement

This thesis endeavors to address the imperative for designing and advancing linear conveyor systems that meet the dynamic requirements of industrial settings. Current challenges in maintaining seamless goods movement on conveyor belts, exacerbated by material or debris adhesion, necessitate innovative solutions to enhance operational efficiency and reliability (Velmurugan et al., 2014). The proposed approach aims to mitigate these constraints through the development of a novel linear conveyor system capable of preventing and minimizing such issues, thereby optimizing goods movement efficiency on the conveyor surface.

Central to the design and development challenges are issues concerning belt operation, including misalignment leading to belt deviation from tail pulleys, resulting in disarray and slippage. These complications stem from factors such as inadequate counterweights, misaligned idlers or pulleys, stresses in adhesive-bonded joints, and accumulation of materials at loading points (Mazurkiewicz, 2009). Proposed solutions encompass recalibration and realignment strategies. The core challenge lies in achieving a balanced mechanical selection and employing appropriate conveyor types to effectively address these operational hurdles.

The complexity inherent in designing and developing linear conveyor systems underscores the necessity for the emergence of technologically robust solutions. The problem statement underscores the pivotal need to ensure that the resultant conveyor system aligns comprehensively with the diverse technological demands of industrial sectors, thereby fostering innovation and practical utility in real-world applications (Pihnastyi & Khodusov, 2019).

1.3 Objective

The objectives of this study are as follows:

I. To determine the design requirement of the cell to cell conveyor system.
II. To design and develop of cell to cell conveyor system.
III. To analyze the functionality and applicability of cells to cell conveyor systems.

1.4 Scope of the Project

The scope of this project encompasses the design and development of a linear conveyor system tailored for industrial applications. Key objectives include the creation of an efficient material handling system capable of accommodating variable angular movements, with a focus on optimizing performance to meet the specific demands of the parcel industry.

Central to the project are the design and engineering aspects, utilizing both 3D and 2D design tools such as Catia V5 and SolidWorks. These software platforms facilitate comprehensive modeling and analysis necessary for achieving optimal conveyor layout, wheel or roller selection, and integration with existing infrastructure at corners.

The manufacturing processes involved in this project span cutting, bending, and joining of materials, utilizing specialized equipment including MIG welding machines, bending machines, laser cutters, and grinders. These processes are critical for fabricating the conveyor components with precision and durability, ensuring they meet industrial standards and operational requirements.

Notably, the project excludes the integration of a PLC (Programmable Logic Controller) system into the conveyor design, focusing instead on mechanical and structural aspects. This deliberate approach allows for a streamlined development process aimed at achieving robust performance and reliability in material handling applications.

Overall, this project represents a comprehensive endeavor in the field of industrial engineering, addressing multifaceted challenges in conveyor system design, material handling efficiency, and manufacturing technology utilization within the context of industrial automation and logistics.

CHAPTER 2

LITERATURE REVIEW

This chapter provides a comprehensive overview of the subject matter that is going to be discussed throughout the rest of this investigation. The evidence for the chosen issues is connected to a review that is backed up by an interpretation drawn from the article, journal, book, and several other sources. This information will be helpful in the production of a thorough overview of the chosen subject, which is something that has to be emphasised throughout the various stages of the study.

2.1 Introduction of cell to cell conveyor

In the landscape of modern industries, the conveyor system stands as a silent but essential workhorse, revolutionizing the way materials are moved within manufacturing plants, distribution centers, and various industrial settings. The need to adapt and use new technologies made the industry evolve into a new era. Connectivity, amount of data, new devices, inventory reduction, customization, and controlled production gave rise to the so-called Industry 4.0. Term created to meet the demands of innovation and changes announced in Germany ‘‘as the fourth industrial revolution’’ (Zonta et al., 2020). At its core, a conveyor system is a mechanical apparatus designed for the efficient transportation of materials from one location to another. This ingenious invention has become an integral component of industrial workflows, offering an automated and reliable means of moving goods, components, and raw materials. A conveyor system is a common piece of mechanical handling equipment that moves materials from one location to another. Conveyor systems allow quick and efficient transportation for a wide variety of materials, which make them very popular in the material handling and packaging industries (Muda et al., 2015).

A cell-to-cell conveyor system denotes an advanced material handling infrastructure designed specifically for facilitating the seamless transportation of goods or components between distinct workstations or processing cells within an industrial or manufacturing context. The term "cell" refers to delineated areas where specific manufacturing or processing tasks are executed.

This conveyor system is characterized by its multidirectional movement capabilities, optimizing spatial efficiency and enabling adaptable routing configurations to align with the layout of manufacturing cells. Emphasis is placed on agile manufacturing processes, aiming to alleviate bottlenecks and enhance overall operational efficiency through the swift and precise transfer of materials. The design considerations encompass meticulous integration with existing infrastructure, customization to meet precise operational requirements, and potential scalability.

The term "cellular conveyor" can refer to different concepts. In the context of material handling systems, "cellular conveyor" or "celluveyor" refers to a modular conveyor technology based on robotic cells that can be assembled into various layouts, offering flexibility, performance, and adaptability. On the other hand, in a biological context, the term "cellular conveyor belt" is used to describe the processes of cell proliferation and differentiation within a structure. Therefore, the type of "cell to cell conveyor" can vary depending on the specific application, such as industrial material handling or biological processes (Condamine et al., 2019).

2.2 Type of cell to cell conveyor

Figure 2.1 Modularity in conveyor systems (Source: Canadian Packaging staff, 2018)

Modularity in conveyor systems refers to the design and implementation of conveyors using interchangeable and standardized components. A modular conveyor system comprises independent sections or modules that can be easily connected or disconnected to adapt to varying production needs. Figure 2.1 allows for flexibility in configuration, scalability for future expansion, and simplified maintenance or modification without disrupting the entire system. By utilizing standardized modules, industries benefit from quicker installation, enhanced adaptability to changing requirements, and improved overall efficiency in material handling processes. Modular conveyor systems can be easily reconfigured to accommodate changes in the production line layout, production schedule, or product types. Conveyor modules can be added, removed, or rearranged quickly (Hanafy & ElMaraghy, 2017).

A conveyor system featuring a hexagonal design pertains to the incorporation of a hexagonal configuration in its structural layout, predominantly in the arrangement of rollers or belts. This geometric orientation is selected for its inherent advantages, such as heightened stability and optimal space utilization. The hexagonal pattern contributes to a more equitable distribution of loads, mitigating stress on individual components and augmenting the overall structural robustness of the conveyor. Moreover, the hexagonal design facilitates multidirectional movement, fostering a seamless flow of materials and heightened adaptability to diverse production layouts. This innovative design paradigm is envisaged to systematically enhance operational efficiency, diminish maintenance requirements, and elevate the reliability of material transportation within industrial contexts. The tubular shape allows the belt to better contain the material, resulting in less spillage risk and the ability to operate under lower belt tensions. This reduces power needs (Molnár et al., 2014).

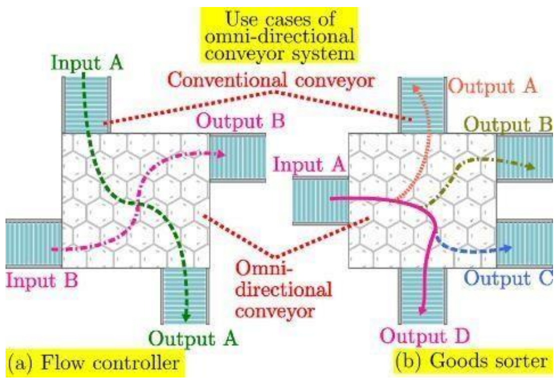


Figure 2.2 Omnidirectional movement conveyor (Source: Muhammad Qomaruz Zaman, 2020)

An omnidirectional movement conveyor is characterized by its ability to move in multiple directions effortlessly, allowing for enhanced flexibility and adaptability in material handling applications. Unlike traditional conveyors that are limited to linear or curved paths, omnidirectional conveyors utilize specialized wheels or rollers to achieve movement in any direction, including forward, backward, sideways, and rotation. Figure 2.2 design facilitates precise positioning and the efficient transport of materials along complex paths. The omnidirectional movement capability is particularly advantageous in scenarios where quick and precise maneuvers are essential, optimizing operational efficiency in industrial settings. Conveyor systems and automated guided vehicles in factories and warehouses that can move laterally tosort goods. Some early concepts for omnidirectional treadmills and virtual reality experiencesto allow walking freely in any direction (Asplund & Luengo Hendriks, 2016).

Figure 2.3 The expandability and adaptability a conveyor system (Source: Conveyor Concept Inc, 2022)

The expandability and adaptability of a conveyor system denote its inherent capability to accommodate variations in scale, configuration, and operational requisites. This design principle underscores the utilization of modular components, facilitating straightforward expansion or modification without necessitating extensive system restructuring. The conveyor's adaptability is manifest in its adeptness at seamless integration with novel equipment and capacity to conform to alterations in production exigencies. This dynamic attribute not only augments scalability but also ensures the conveyor system's responsiveness to evolving industrial demands, thereby optimizing operational efficiency and prolonging its applicability in diverse manufacturing contexts. The system uses individual sensor modules and drive control modules for each section/stage of the conveyor. Additional sections can be added by introducing new modules, without reconfiguration of existing infrastructure (Li et al., 2019).

2.3 Working principle of cell to cell conveyor

A cell-to-cell conveyor system, also known as a transfer conveyor, facilitates the seamless and efficient movement of materials or products between individual cells or stations along a production or processing line. The operational principles and functionality of a cell-to-cell conveyor are designed to optimize the flow of materials, streamline processes, and enhance overall production efficiency.

Material Loading at Source Cell: The process begins with the loading of materials or products onto the conveyor at the source cell. This cell is typically a designated station where items are introduced to the conveyor system. The paper analyzes noise in the load cell signal of an automatic weighing system with a belt conveyor. The noise contains vibration from the conveyor operation and environmental noise (Choi, 2017).

Conveyor Movement: Once the materials are loaded, the conveyor system is activated. The conveyor belt or other conveying mechanism starts moving, transporting the materials along the predetermined path towards the destination cell. The fiber lay-down process is modeled by a stochastic differential equation tracking the position and angle of a fiber at the point where it touches a moving conveyor belt (Bouin et al., 2017).

Transfer Mechanism: At the destination cell or station, a transfer mechanism comes into play. This mechanism is designed to facilitate the smooth transfer of materials from the conveyor to the next stage of the production process or to another conveyor line. The transfer mechanism constitutes a pivotal constituent of the conveyor system, facilitating the expeditious relocation of materials across distinct phases of the production process. The celluveyor, an exemplar of contemporary modular conveyor technology grounded in robotic cells, serves as a state-of-the-art instance of a cell-to-cell conveyor system that leverages transfer mechanisms for the seamless conveyance of materials between cells. Distinguished by its hexagonal hardware module design, the celluveyor offers a versatile layout configuration, and its cells are programmable through software, thereby optimizing material flow efficiency. The system's omnidirectional movements, coupled with independently driven wheels per cell, engender intricate material flow patterns with a minimal spatial footprint. The celluveyor's efficacy is further heightened by its intelligent control system and modular design, facilitating facile expansion and adaptation to evolving requirements without necessitating extensive efforts. This amalgamation of cutting-edge hardware and software elements epitomizes the sophistication inherent in the celluveyor, positioning it as an innovative solution for intricate material handling scenarios within contemporary industrial contexts (Shih et al., 2019).

Adjustable Length Movements: In the case of a cell-to-cell conveyor with adjustable angle movements, the conveyor system may be equipped with mechanisms allowing for changes in the conveying angle. This feature adds flexibility to the system, accommodating variations in production requirements. E. coli cells were assembled into a bio-conveyor belt with an adjustable length using two fiber probes. The diameter of the belt was smaller than the laser wavelength, allowing an evanescent wave to emerge around it (Liu et al., 2019).

Material Unloading at Destination Cell: The materials are unloaded at the destination cell, where they can undergo further processing, assembly, or any other necessary operation. The destination cell may represent a specific stage in the production line or serve as a transfer point to another conveyor system. The celluveyor, an innovative modular conveyor technology grounded in robotic cells, is purposefully engineered to facilitate material handling and movement within the designated system. Although explicit details regarding the intricacies of the material unloading process remain unavailable within the provided sources, the celluveyor's conspicuous attributes of flexibility, performance, and adaptability substantiate its inherent capacity to effectively manage the material unloading procedures at destination cells within the overarching system. The modularity and robotic foundation of the celluveyor, underscored by its adaptable design, collectively suggest a sophisticated capability to address the nuanced requirements associated with material unloading operations, contributing to the system's overall efficiency in material flow and logistics (Keek et al., 2021).

The design and development of smart cell-to-cell conveyor systems involve understanding how these systems work and their various components. In this context, a smart conveyor system is one that can track individual materials in real-time, including their speed, direction, and position. Smart conveyor systems use the latest automation components to achieve their uniqueness over conventional conveyors. Some of these components include motion control, artificial intelligence (AI), and smart sensors. The design and development of smart cell-to-cell conveyor systems involve understanding how these systems work and their various components. In this context, a smart conveyor system is one that can track individual materials in real-time, including their speed, direction, and position. Smart conveyor systems use the latest automation components to achieve their uniqueness over conventional conveyors. Some of these components include motion control, artificial intelligence (AI), and smart sensors.-An example of a recent advancement in conveyor technology is the development of the E-Pattern Omniwheeled Cellular Conveyor (EOCC), which represents a significant innovation in the field. This system, detailed in a 2021 study, introduces a novel design and control setup for an omniwheeled cellular conveyor, showcasing the ongoing evolution of conveyor system design and technology (Keek et al., 2021).

2.4 Method in developing conveyor

The state of the art in developing conveyor systems involves the integration of advanced methods and technologies to enhance efficiency, flexibility, and sustainability. Several notable trends and methodologies characterize the current state of conveyor development.

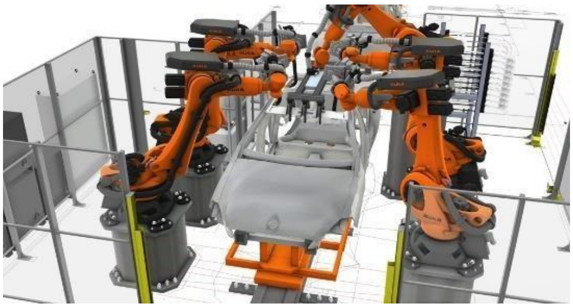


Figure 2.4 3D Modeling and Simulation (Source: Visual Components, 2016)

3D Modeling and Simulation: The use of advanced 3D modeling software allows engineers to design and simulate conveyor systems with precision. This aids in visualizing the system's layout, identifying potential issues, and optimizing the design before physical implementation. Simulating complex construction operations through discrete event modeling can provide useful insights, but decision makers often lack the means to verify the accuracy of the models (Kamat & Martinez, 2003).

Figure 2.5 Digital Twins (Source:Smart Industry Solution, 2019)

Digital Twins: Implementation of digital twin technology, where a virtual replica of the conveyor system is created and linked to its physical counterpart. This enables real-time monitoring, predictive maintenance, and performance optimization. Digital twins can provide valuable insights through simulation and analysis that can improve system designs, optimize operations and maintenance, uncover problems early, and reveal new applications (Sundby et al., 2021).

Smart conveyors, based on frameless linear motor technology, offer both speed and flexibility to address the modern need for variety in manufacturing. They incorporate linear encoders, enabling the system to monitor the location of each cart at all times, making the technology useful for more than just manufacturing.-The importance of smart cell-to-cell conveyor systems lies in their ability to provide efficient material handling, collision avoidance, energy efficiency, predictive maintenance, reduced downtime, integration with other technologies, modularity, flexibility, reduced space requirements, improved manufacturing efficiency, data collection and analysis, and cost-effectiveness (Kumar, 2017.).

2.5 Tools for Design and Development of conveyor

The state of the art in tools for the design and development of conveyor systems includes various methodologies, techniques, and technologies that help in creating efficient and effective conveyor systems. These tools enable the identification of key requirements, optimization of material flow, and development of innovative solutions for various industries.

Industry Requirements Analysis: Analyze the specific needs of various industries to identify the key requirements for conveyor systems, such as speed, precision, flexibility, and integration with other technologies (Van Vianen et al., 2016).

Expert Interviews and Collaborations: Engage with experts in the field, such as engineers, automation specialists, and logistics professionals, to gather insights and suggestions on the design and development of conveyor systems (Mousavi et al., 2005).

Literature Review: Conduct a comprehensive literature review on existing conveyor technologies, their limitations, and emerging trends to identify potential design and development tools for smart conveyor systems. Integrative literature reviews are a form of research that use existing literature to generate new perspectives and knowledge on a topic. They are well-suited for reviewing mature topics that would benefit from an update and critique or emerging topics that would benefit from an initial conceptualization (Torraco, 2016).

Prototyping and Testing: Develop and test various prototypes of smart conveyor systems to evaluate their performance and identify areas for improvement, which can help refine the design and development tools (Henderson et al., 2007).

User Feedback and Evaluation: Conduct user testing with the prototypes to gather feedback and evaluate the effectiveness of the design and development tools, making necessary adjustments to improve the conveyor system's performance (Van Vianen et al., 2016).

Benchmarking: Compare the design and development tools of smart conveyor systems with existing conveyor technologies and emerging trends to identify areas for improvement and potential innovations (Van Vianen et al., 2016).

Design Principles and Guidelines: Review design principles and guidelines for conveyor systems, such as the six performance considerations for conveyor selection (maximum throughput per time unit, geometry of the material to be transported, weight and material of the transported product, control requirements, and environmental conditions) (Henderson et al., 2007).

Stakeholder Engagement: Collaborate with stakeholders, such as manufacturers, users, and industry experts, to discuss and refine the design and development tools for smart conveyor systems (Vijay, 2015).

Iterative Process: Continuously iterate on the design and development tools based on feedback, testing results, and industry trends to ensure the development of an effective and efficient smart conveyor system (Mousavi et al., 2005).

Learning Transformation: Leverage learning transformation, a process that focuses on rethinking traditional teaching methods and increasing student-centered approaches, to enhance the design and development of conveyor systems. Spiritual learning moments involve experiences of "grace" or insight that provide hope, healing, or direction during difficult times. Making sense of these moments is an ongoing process (Foote, 2015).

CHAPTER 3

METHODOLOGY

In this chapter, the methodology will cover the methods, techniques and approaches used to achieve the objectives and goals of the study. The methodology applied makes the study conducted more systematically and the course of study is more directed in achieving objective. This chapter will explain the research methodology used in the study conducted.

3.1 Design Requirements to Fabricate a Cell to Cell Conveyor System

Design requirements are fundamental specifications and constraints that provide essential direction for the development of a product, system, or project. These requirements establish the necessary functionalities, performance standards, and user expectations, serving as the cornerstone of the design process.

The product development process initiates with idea generation and problem or opportunity identification, involving thorough observation of target users to understand their specific needs. This phase aims to gather comprehensive insights that will inform subsequent design decisions.

The House of Quality matrix is employed to prioritize design decisions based on identified customer requirements, ensuring that the final product aligns closely with user expectations. Evaluating the sufficiency of gathered data is critical before proceeding to further stages of development.

The final stage of the product development process encompasses gathering market information to identify existing conveyor systems and conducting benchmarking activities to compare performance against established references. These steps contribute to refining design choices and ensuring that the resulting product meets or exceeds industry standards and user needs.

Figure 3.1 depicts a flowchart illustrating the process of designing requirements for fabricating a cell-to-cell conveyor system, emphasizing the systematic approach from initial idea generation to final product realization. This structured methodology ensures that design decisions are informed, validated, and aligned with both market demands and user requirements, thereby enhancing the overall effectiveness and success of the product development endeavor in industrial contexts.

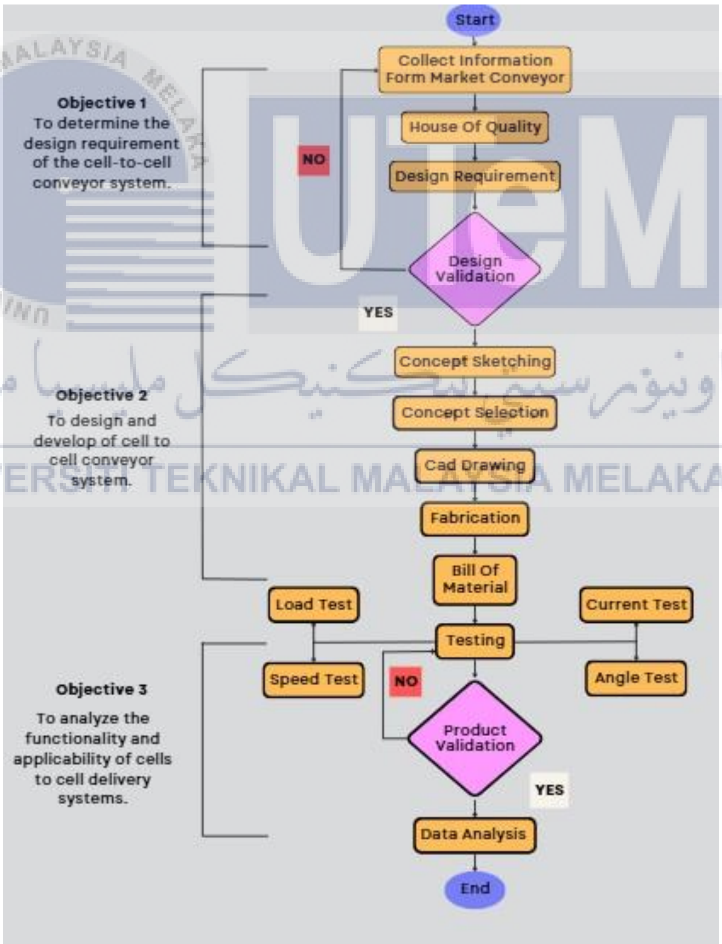


Figure 3.1: Flowchart of this project

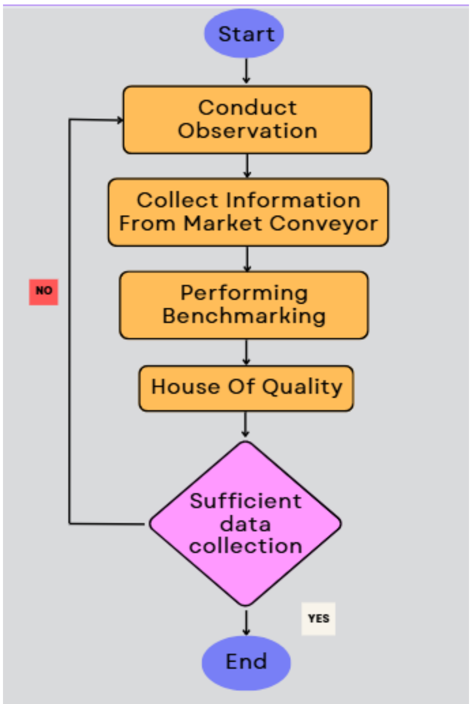


Figure 3.2: Flowchart of developing the design requirements.

3.1.1 Conduct Observation

Designing a product without comprehensive knowledge and thorough observation is frequently undervalued. A user's proficiency in using a product allows for an understanding of its capabilities, while deep knowledge enhances research experience. Observation, distinct from merely hearing about a product, entails witnessing a process, action, or interaction with a good or service firsthand and this observation is targeted at users like the factory.

Repeated and meticulous observation enables scrutiny of every detail, facilitating an assessment of whether the product effectively achieves its intended objectives. This approach ensures that design decisions are grounded in empirical data and practical insights, thereby enhancing the likelihood of creating products that meet user expectations and operational requirements in various contexts.

3.1.2 Collect Information form Market Conveyor

The process of gathering market information on conveyor systems requires a systematic approach that aims to obtain as many as 10 relevant data and insights on various aspects such as technological advancements, industry trends, competitive dynamics and customer needs.

To begin, it is crucial to clearly define the research objectives, outlining specific areas of interest within the realm of conveyor systems. These objectives may encompass investigating technological innovations, analyzing prevailing market trends, understanding customer preferences, assessing the competitive landscape, and evaluating regulatory influences.

By delineating these objectives clearly, the research effort can be focused and targeted, ensuring that the gathered information is comprehensive and relevant to the specific needs of stakeholders involved in the design, development, or utilization of conveyor systems. This systematic approach facilitates informed decision-making and strategic planning within the industry, ultimately contributing to the enhancement of product development, market positioning, and overall operational effectiveness in the field of conveyor system technology.

3.1.2.1 Product specification.

This section will explain the product specification required in the omnidirectional conveyor product during the developing process by performing the user need translation, technical specification, similar product benchmark, and the house of quality analysis approaches.

3.1.2.1.1 Translation of each User Needs.

Here are the product specifications for omnidirectional conveyor products derived from survey analysis by translating user needs.

1) Performance and Efficiency

i. **Speed and Durability**: The system should handle high volumes of material with efficient movement to maintain or increase production rates.
ii. **Payload Capacity**: The ability to transport various sizes and weights of loads without compromising performance.

2) Flexibility and Adaptability

i. **Multi-Directional Movement**: The ability to move in any direction (forward, backward, sideways and rotational) to navigate complex paths and tight spaces.
ii. **Scalability**: The ability to easily expand or reconfigure the system as production demands grow or change.
iii. **Versatile**: Suitable for a wide range of materials and packaging, from small parts to large pallets.

3) Safety and Ergonomics.

i. **Employee Safety**: Safety features to prevent accidents, such as emergency stops, safety guards, and collision avoidance systems.
ii. **Ergonomics**: Designs that minimize physical stress on workers, such as easy access for loading and unloading.

4) Reliability and Maintenance.

i. **Durability**: Robust construction to withstand harsh industrial environments, including exposure to dust, chemicals and extreme temperatures.
ii. **Low Maintenance**: Minimal maintenance requirements with easy access to components for repair and replacement.

5) Cost and ROI.

i. **Initial Investment**: Competitive pricing that fits operating budget constraints.
ii. **Operating Costs**: Energy efficient systems that minimize operating costs.
iii. **Return on Investment (ROI)**: Clear benefits in terms of productivity, efficiency and cost savings over time.

6) Customization and Support.

i. **Customization Options**: The ability to customize the system to meet specific operational requirements, including size, speed, and load handling characteristics.
ii. **Technical Support**: Availability of robust customer support and training services for installation,

operation and troubleshooting.

7) Environmental Considerations.

i. **Energy Efficiency**: Systems that use less power and contribute to lower overall energy consumption.
ii. **Sustainability**: The use of environmentally friendly materials and processes in the manufacture of the conveyor system.

3.1.2.1.2 Technical Specification.

The technical specifications for omnidirectional industrial conveyor systems are detailed criteria that ensure the system meets performance, safety, and operational standards. Below are the key technical specifications:

1) Mechanical specifications.

i. **Load Capacity**: Maximum load weight per unit area (eg, kg/m^2).
ii. **Conveyor Speed**: Adjustable speed range (eg, 0.1 to 2 meters per second).
iii. **Dimensions**: Length, width and height of the conveyor unit, including the size of the modular parts.
iv. **Material Handling Capacity**: The type and size of material that can be handled (eg, pallet size, box dimensions).
v. **Drive System**: The type of drive mechanism used (eg, electric motor, servo motor).

2) Movement Ability.

i. **Degrees of Freedom**: Number of axes of movement (eg, forward/backward, lateral, rotational).
ii. **Movement Accuracy**: Position and movement accuracy (eg, ±1 mm).

3) Safety features.

i. **Emergency Stop**: Presence and type of emergency stop mechanism.
ii. **Collision Avoidance**: The type of collision avoidance system used.

4) Construction and Durability.

i. **Frame Material**: The type of material used for the conveyor frame (eg, stainless steel, aluminum).
ii. **Surface Material**: Type of conveyor surface (eg, rubber, PVC, metal roller).
iii. **Durability**: Specifications on operational life and maintenance intervals.
iv. **Environmental Resistance**: Resistance to environmental factors (eg, temperature range, humidity, chemical exposure).

5) Power and Energy Specifications.

i. **Power Supply**: Voltage and frequency requirements (eg, 220V, 50/60Hz).
ii. **Energy Consumption**: Average and peak power consumption (eg, kWh).

6) Environmental Specifications.

i. **Operating Temperature Range**: Minimum and maximum operating temperature.
ii. **Humidity Range**: Acceptable humidity level for operation.
iii. **Sound Level**: Maximum noise output (eg, dB level).

7) Maintenance and Serviceability.

i. **Maintenance Requirements**: Regular maintenance tasks and intervals.
ii. **Accessibility**: A design feature that allows easy access for maintenance and repair.
iii. **Spare Parts Availability**: Spare parts availability and specifications.

8) Customization Options.

i. **Modularity**: Ability to add or remove parts.
ii. **Configuration Options**: Different configurations for specific applications (eg, heavy duty, high speed).
iii. **Custom Features**: Availability of custom features to meet specific user needs.

3.1.2.1 Identify Information Sources

The review of product specifications, technical datasheets, and white papers published by manufacturers and suppliers of conveyor systems provides valuable insights into the capabilities, features, and application-specific solutions offered by these products.

Product specifications outline detailed information regarding the technical attributes, dimensions, capacities, and operational parameters of conveyor systems. These specifications serve as a foundational reference for understanding the performance capabilities and limitations of different conveyor models.

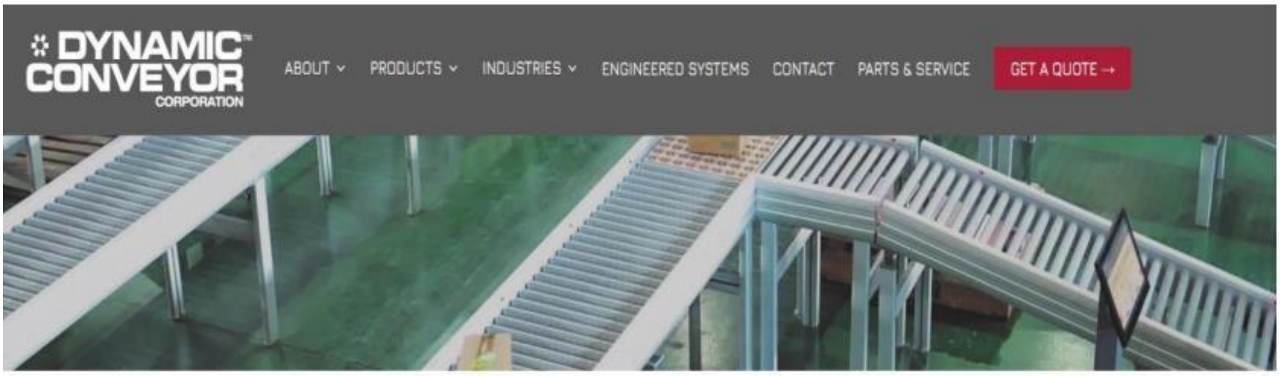
Technical datasheets complement product specifications by providing additional technical details, such as material specifications, motor specifications, power requirements, and environmental considerations. These datasheets are crucial for engineers and designers in assessing the compatibility and suitability of conveyor systems for specific industrial applications.

White papers published by manufacturers and suppliers offer in-depth analyses, case studies, and application examples that demonstrate the performance and efficiency of conveyor systems in various operational scenarios. These documents often highlight innovative features, technological advancements, and best practices in conveyor system design and implementation.

3.1.3 Perform Benchmarking

3.1.3.1 Similar Product 1.

Product Name: Dynamic Conveyor (Dynamic Conveyor, 2024)



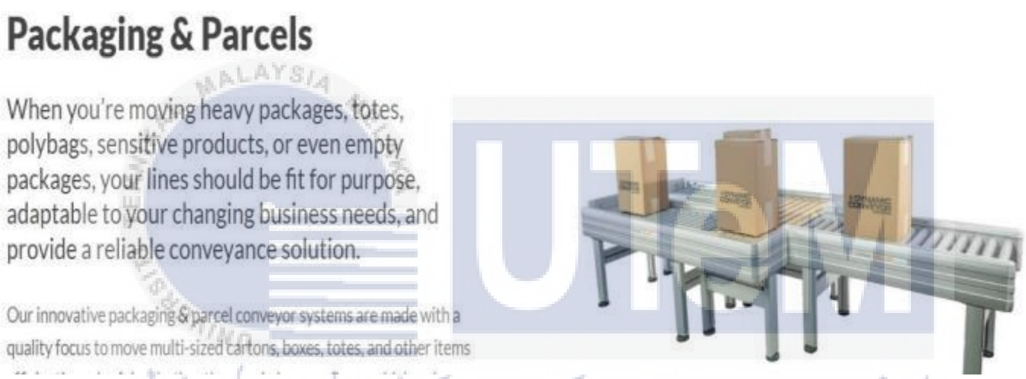


Figure 3.3: Dynamic Conveyor.

Product Description.

Dynamic Conveyor Corporation produces advanced conveyor systems that aim to increase efficiency and productivity in material handling processes. Our offerings include customizable modular conveyors, customizable DynaCon systems, hygienic DynaClean conveyors for food handling, and bespoke hybrid specialty conveyors. In addition, we provide a wide range of accessories and options, including conveyor belts, side guards, motor configurations and automation solutions. Choose Dynamic Conveyors to benefit from a flexible, robust and environmentally sustainable solution that improves operational performance.

The key features of the Dynamic conveyor include:

• Customizable Modular Conveyors: Easily adjustable and reconfigurable to meet changing needs.
• Versatile DynaCon Systems: Tailored designs for specific operational requirements with easy maintenance.
• Sanitary DynaClean Conveyors: Hygienic and easy to clean, ideal for food handling and compliant with safety standards.
• Hybrid Specialty Conveyors: Custom-engineered solutions for unique and challenging applications.
• Comprehensive Accessories and Options: A variety of conveyor belts, side guards, motor options, and automation systems to enhance functionality and efficiency.

Functionality.

Dynamic Conveyor systems are designed to efficiently transport materials within industrial settings. They offer:

• Customizability: Modular designs that can be easily adjusted and reconfigured to fit specific operational needs.
• Versatility: Suitable for a wide range of applications, from general material handling to specialized processes like food handling.

• Reliability: Robust construction using high-quality materials ensures durability and long-term performance.

Advantages.

• Flexibility: Modular components allow for easy adaptation to changing production requirements.
• Efficiency: Enhances workflow by streamlining material handling processes.
• Customization: Tailored solutions cater to unique operational challenges, improving overall efficiency and productivity.
• Hygiene: DynaClean conveyors meet food safety standards with easy-to-clean designs, reducing contamination risks.

Disadvantages.

• Cost: Initial investment and maintenance costs can be higher compared to standard conveyor systems.
• Complexity: Custom configurations may require specialized knowledge for installation and maintenance.
• Space Requirements: Depending on the configuration, modular systems may occupy more floor space than traditional conveyor setups

3.1.4 House Of Quality

The House of Quality (HoQ) is a methodological framework utilized in engineering design to systematically capture and analyze the interplay between customer requirements and technical specifications. It comprises a matrix that establishes correlations between various engineering characteristics or parameters and the specific needs and desires of users. This tool assigns relative importance to each requirement and evaluates the strength of their relationships.

Visual representations within the House of Quality matrix aid in prioritizing design decisions, identifying potential trade-offs, and ensuring alignment of project objectives with customer expectations. By visually mapping out these relationships, the House of Quality enables engineers and designers to make informed decisions throughout the design process, emphasizing customer-centric approaches and enhancing overall project efficiency.

The implementation of the House of Quality fosters effective planning and execution of the design process, emphasizing customer satisfaction and ensuring that engineering solutions meet or exceed user expectations. Figure 3.3 exemplifies the application of a House of Quality matrix, illustrating its structured approach to integrating customer needs into the design and development phases of engineering projects.

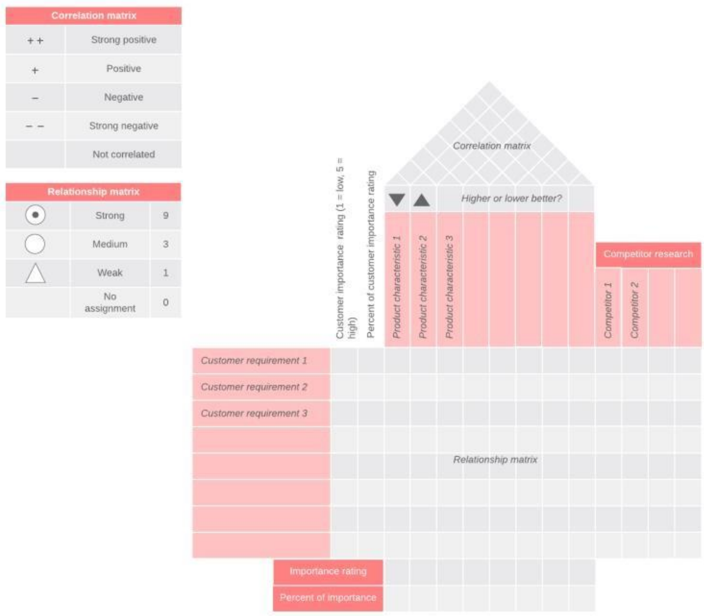


Figure 3.4: House of Quality (Source: Lucidchart, 2018)

Next, a list of design criteria will be presented horizontally at the top. With user needs and design requirements, these two will be measured in the relationship matrix to measure the parameters of how strong the relationship between these two is. The scale will be rated +9 for strong, +3 for medium, +1 for weak and 0 for no relationship at all. Table 3.1 shows the relationship matrix.

Table 3.1: Relationship matrix.

Strong	9
Mediam	3
Weak	1
No correlation	0

In the correlation matrix section, it is necessary to locate the correlation matrix to ascertain how closely related the design criteria are to one another. A "+" symbol in this correlation matrix denotes a positive correlation, a "-" symbol denotes a negative correlation, and an empty symbol denotes no correlation between any two variables. Table 3.2 shows the correlation matrix.

Table 3.2: Correlation matrix.

Correlation matrix	
++	Strong Positive
+	Positive
-	Negative
- -	Strong Negative
	No Correlation

3.1.5 Material Selection

This section outlines the material selection methodology applied in the development of a cell to cell conveyor. The process encompasses several distinct stages, including translation, screening, and ranking, each contributing to the comprehensive evaluation and eventual selection of materials tailored to the specific requirements of the conveyor.

3.1.5.1 Translation of Design Requirements

To discern the constraints influencing material selection, it is crucial to consider the specific requirements of the project or application. This entails understanding factors such as load capacity, corrosion resistance, weight limitations, and the desired lifespan. Table 3.3 illustrates the translation of process requirements for the conveyor prototype.

Table 3.3: Design requirements for frame of cell to cell conveyor.

Element in Design Requirement	Explanation
Function	Provide support when the parcel passes through.
Objective	• Maximize strength. • Minimize weight. • Maximize Stiffness
Constraint	• Density < 2900 kg/m3 • Toughness < 35 MPa • Strength > 150 MPa
Free Variable	• Choice of Materia

The structural configuration of the passive exoskeleton's frame is conceptualized using a model resembling a plate. The governing equations pertaining to the structural characteristics are as follows:

$$k = \frac{F}{\delta} = \frac{3EI}{L^3} \qquad \text{Equation (1)}$$

$$I = \frac{hb^3}{12} = \frac{A^2}{12} \qquad \text{Equation (2)}$$

$$m = \rho AL \qquad \text{Equation (3)}$$

Substituting (2) into (1):

$$k = \frac{3EA^2}{12L^3} \qquad \text{Equation (4)}$$

$$A = \left(\frac{12L^3k}{3E}\right)^{\frac{1}{2}} \qquad \text{Equation (5)}$$

Substituting (5) into (3):

$$m = (\rho L)\left(\frac{12L^3k}{3}\right)^{\frac{1}{2}} \qquad \text{Equation (6)}$$

$$m = \left(\frac{\rho}{E^{\frac{1}{2}}}\right)\left(\frac{12L^4k}{3}\right)^{\frac{1}{2}} \qquad \text{Equation (7)}$$

$$m = \left(\frac{\rho}{E^{\frac{1}{2}}}\right)(4L^4k)^{\frac{1}{2}} \qquad \text{Equation (8)}$$

Where k = stiffness, E = Young's modulus, I = second moment of area, L = length of beam, w = width of beam, ρ = density, A = cross sectional area of beam.

From equation (6), it can be inferred that minimizing the mass, m of the cell to cell conveyor frame will result in a reduction of the frame's stiffness. also, or in other words, maximizing in order to improve the performance of the frame. Hence, through an analysis of the equation, it can be deduced that the choice of material for designing the cell to cell conveyor frame should be based on the material index situated at a slope value of 2.

3.1.5.2 Screening of Material Selection

The translated design criteria constitute the fundamental parameters for implementing a screening methodology, with the objective of excluding material candidates deemed impractical. In the context of this analysis, the CES Edu Pack 2022 program is utilized, and an examination is conducted on the data sourced from the level 2 database. The comprehensive representation of the entire material universe is illustrated in Figure 3.5.

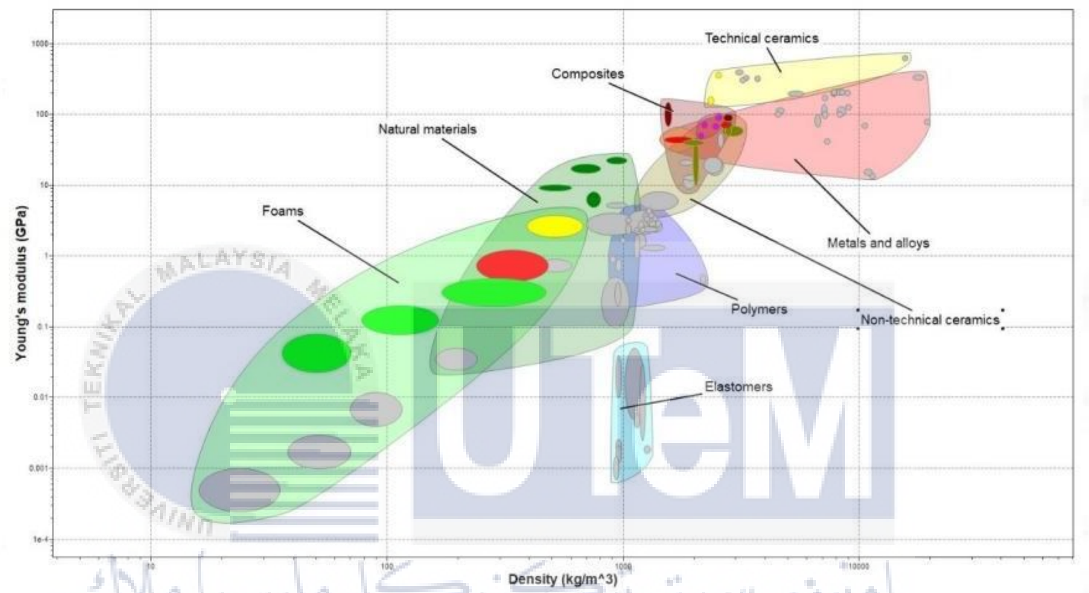


Figure 3.5: Ashby Chart of Young's Modulus over Density

Subsequent to defining the design constraints, the CES Edu Pack software is utilized to input these parameters, effectively eliminating materials that do not conform to the specified limitations. Prescribed criteria include a maximum density of 2900 kg/m³, a minimum fatigue strength of 150 MPa, and a minimum fracture toughness of 35 MPa, aimed 57 at averting catastrophic material failure. Additionally, considerations encompass material resistance to corrosion and the attainment of a favorable surface finish. Materials exhibiting excellence in these aspects are prioritized. The outcomes of this material filtration process are depicted in Figure 3.6.

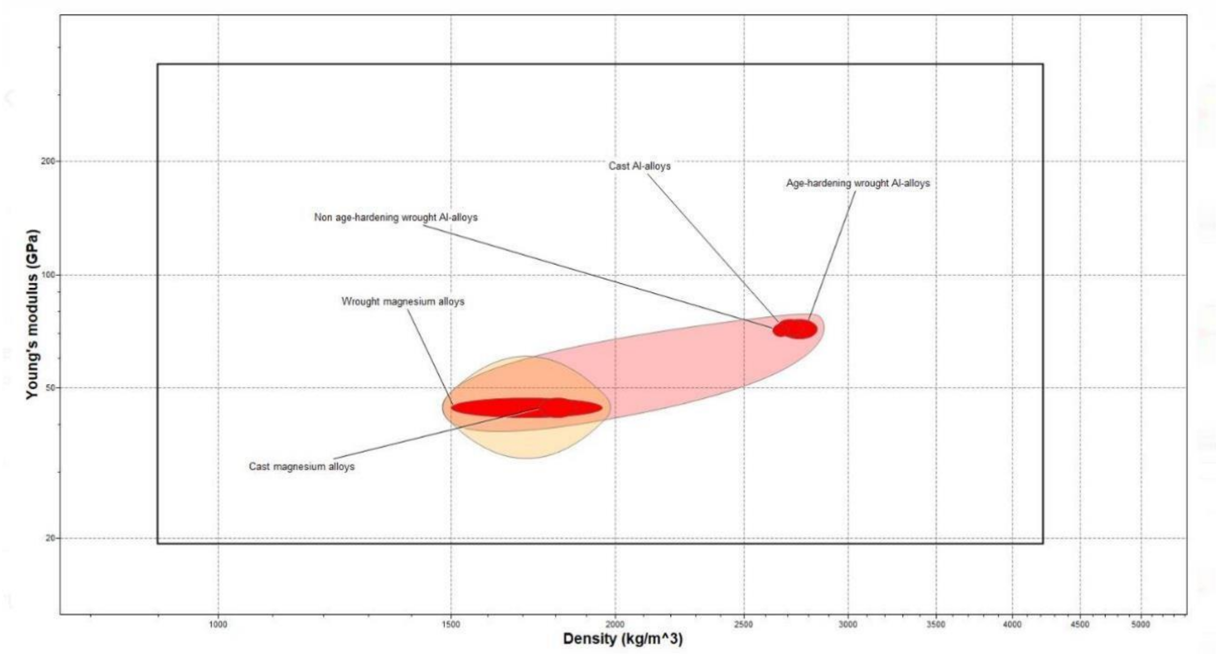


Figure 3.6: Material within the specified constraints

3.1.5.3 Ranking of Material Selection

The utilization of material ranking is integral to the ordered assessment of selected materials, identified during the screening phase, based on their intrinsic properties earmarked for the construction of the frame structure essential to the cell to cell conveyor. This systematic ranking procedure is systematically executed to pinpoint the materials most conducive to the effective development of the designated frame structure for the cell to cell conveyor. The outcomes of this evaluative process, inclusive of the recommended materials and their corresponding material properties, are comprehensively detailed in Table 3.4, elucidating the discernments derived from the implementation of the screening technique.

Table 3.4: Properties of the chosen materials

Material / Properties	Age - Hardening Wrought Al-Alloys	Non – Age Hardening Wrought Al-Alloys	Cast Alloy	Cast Magnesium Alloy
Density (Kg/m^3)	$2.67x10^3$ – $2.84x10^3$	$2.63 x10^3$ – $2.7x10^3$	$2.65x10^3$ – $2.77x10^3$	$1.75x10^3$ – $1.87x10^3$
Young Modulus (GPa)	68 – 80	69 – 74	69 – 78	42 – 47
Fatigue Strength (MPa)	100 – 219	61.7 – 150	63 – 136	60 – 125
Fracture Toughness (MPa m^0.5)	25.7 – 41	27 – 37	19 – 30.9	12 – 18

Based on the data provided in Table 3.5, the selected materials will undergo a ranking process according to the requisite material properties crucial for the development of the cell to cell conveyor. Each chosen material will be assigned a numerical value corresponding to its position within the ranking system, as illustrated in Table 3.5. Utilizing a scale ranging from 1 to 5, where 1 denotes the lowest and 5 signifies the highest performance, a higher cumulative value indicates superior performance of the materials.

Table 3.5: Ranking of the chosen materials.

Material / Properties	Age - Hardening Wrought Al-Alloys	Non – Age Hardening Wrought Al-Alloys	Cast Alloy	Cast Magnesium Alloy
Density (Kg/m^3)	3	3	4	5
Young Modulus (GPa)	3	3	5	4
Fatigue Strength (MPa)	5	4	3	2
Fracture Toughness (MPa m^0.5)	5	4	2	1
Total Score	16	14	14	12

According to the information presented in Table 3.5, it is evident that Age-hardening wrought Al-Alloys are selected as the preferred material for constructing the frame of the dough cooling shelf. This decision is based on their notably high-ranking value for performance in comparison to alternative materials, including Cast Al-Alloy, Non-agehardening wrought Al-Alloys, Cast Magnesium-Alloy, and Wrought Magnesium Alloy, as indicated in the aforementioned material ranking table.

3.1.5.4 Documentation of Material Selection

The documentation pertaining to the material characteristics of Age-hardening wrought Al-Alloys is presented in Table 3.6, providing detailed information on the properties of the material.

Table 3.6: Documentation of the chosen material

Material	Description
Age-hardening Wrought Al-Alloys	Age-hardening wrought aluminum alloys are widely used as structural materials due to their favorable characteristics, making them suitable for various applications. These alloys are chosen for their lightweight nature, moderate cost, and impressive mechanical performance, which encompasses specific stiffness, specific strength, ductility, and fracture toughness. The strength of aluminum alloys is achieved through a combination of mechanisms, including solid solution hardening, work hardening, and grain boundary hardening. However, the primary mechanism responsible for strengthening is precipitation hardening. This process results in a high Young's modulus value of 80 GPa and a tensile strength value of 620 MPa. These mechanical properties make aluminum the most prevalent choice as a structural material for developing prototypes, surpassing other metal elements in this regard.

3.2 Design and Develop a Cell to Cell Conveyor

The product development process begins with the collection of ideas and the comprehension of the issue or opportunity. Following that, basic drawings of prospective concepts are created. Based on criteria, the concept screening matrix assesses and compares concepts. After that, a precise 3D model is generated and evaluated for accuracy. Before proceeding to production preparation, adjustments may be made. The last stage of the process involves preparing the product for its intended usage. Figure 3.7 shows the flowchart of design and fabricate a cell to cell conveyor.

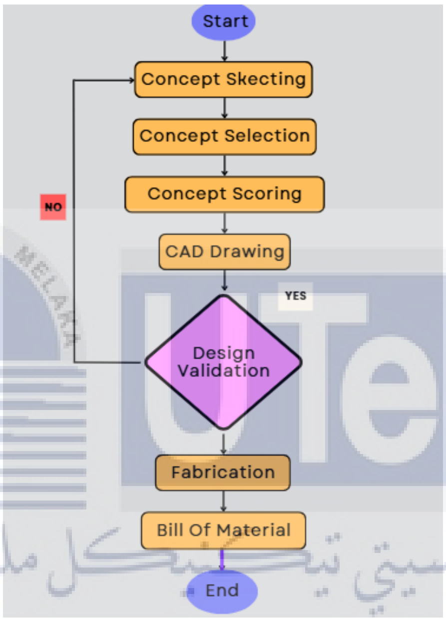
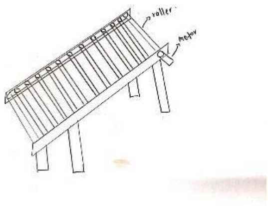
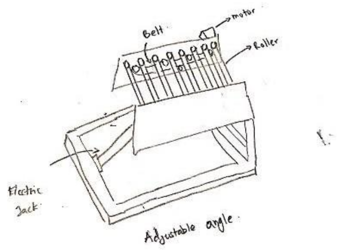
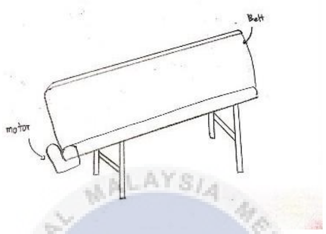
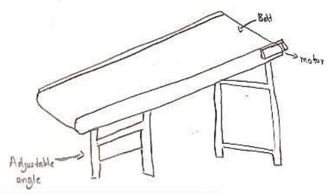
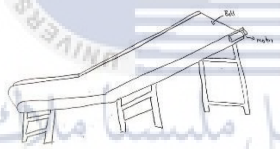


Figure 3.7: Flowchart of develop a cell to cell conveyor.

3.2.1 Conceptual Sketching

During the concept design phase, multiple designs are generated based on a variety of collected criteria, aiming to provide a comprehensive visual depiction. This method is intended to ensure that the prototype being developed faithfully embodies the insights gleaned from gathered information. Preliminary drawings serve as a pivotal tool for forming initial impressions and devising straightforward solutions regarding the product's structure, operational methodology, intended applications, and essential features. The conceptual design of the discussed product is detailed in Table 3.7, presenting different design iterations formulated during this stage of product development. These designs serve to encapsulate the core functionalities and attributes envisioned for the product, setting the stage for further refinement and prototyping phases.

Table 3.7: Product conceptual design.

<table>
<tr><th>Concept</th><th>Design</th><th>Concept</th><th>Design</th></tr>
<tr><td>A</td><td>
</td><td>D</td><td>
</td></tr>
<tr><td>B</td><td>
</td><td>E</td><td>
</td></tr>
<tr><td>C</td><td></td><td></td><td></td></tr>
</table>

3.2.2 Concept Selection

The process of concept screening is an important step that involves ranking prospective ideas in order of importance. It entails evaluating each idea in a methodical manner based on a set of predetermined criteria such as whether or not it is feasible and whether or not it aligns with the project's goals. Concept screening, which involves thorough review, helps filter out less viable concepts so that attention may be focused on those that are the most viable and have the most impact. This procedure maximizes the use of available resources, reduces risk, and guarantees that the objectives of the project are met. The successful screening of concepts paves the way for the selection and pursuit of ideas that have the highest potential for achievement, which ultimately results in outcomes that are relevant and effective for the final year project.

The first step should be to create a table outlining the standards and concepts used in this method. The selection criteria must be related to the needs of the client in some way, and concepts must be traced back to those that were conceived through conceptual sketching. After the matrix had been created, (+, 0 and -) symbols were placed in each category to be evaluated by comparison to the reference notion. The (+) symbol denotes "better than," the (0) symbol denotes "the same as," and the (-) symbol denotes "worse than" depending on the concept reference. The frequency of the rating scales for each concept have been merged, and the net score for each concept may be obtained by deducting the frequency of "-" from the frequency of "+". Each concept's significance was assessed based on how well it performed in comparison to the other concepts. It was decided whether to eliminate the 64 thought with the lowest score or to combine two concepts, preserving just the features denoted by a "+". The initial concepts had been reduced to two to three by the end of the concept screening stage, which would then be further developed in subsequent investigations. Table 3.8 below shows the framework for the concept screening method.

Table 3.8: Framework of concept screening

Selection criteria	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
Criteria 1						
Criteria 2						
Criteria 3						
Criteria 4						
Sum '+' s						
Sum '0' s						
Sum '-' s						
Total						
Rank						
Continue						

3.2.3 Concept Scoring

The scoring of concepts is a method that is used to evaluate and rank possible ideas based on a set of predetermined criteria. Using a method that is structured around scoring, the rating or score that is provided to each idea indicates its performance or degree of accomplishment in comparison to certain criteria that have been established beforehand. The rating scale that is used while assessing an idea might change based on the particular project and assessment procedure being employed. In most cases, a numerical rating scale is used, such as a scale ranging from 1 to 10 or 1 to 5, in which higher numbers imply greater performance or alignment with the assessment requirements. Table 3.9 shows the rate for concept scoring rating.

Table 3.9: Rate for concept scoring rating

Relative Performance	Rating
Poor than reference	1
Fair than reference	2
Same as reference	3
Good than reference	4
Excellent than reference	5

A concept scoring system will decide how the various ratings and criteria will be added together to get a final score for each idea. This phase entails creating a formula or weighting scheme that indicates the relative weights assigned to each assessment criteria. Each criterion is given a weight or priority factor by the weighting system depending on how important it is to attain the project's goals. Usually, these weights are stated as ratios or percentages. The individual criteria ratings are multiplied by the weights that correspond to them once they have been awarded, and then the total is used to get the overall score for each idea. This offers a quantitative measurement that takes into account the relative weights assigned to each criterion in the assessment. Table 3.10 shows the finalised of concept scoring.

Table 3.10: Rate for concept scoring rating.

Evaluation Criteria	Weight (%)	Concept A		Concept B		Concept C	
		Ranking (1-5)	Weight score	Ranking (1-5)	Weight score	Ranking (1-5)	Weight score
Criteria 1							
Criteria 2							
Criteria 3							
Criteria 4							
Criteria 5							
Total Score							
Rank							
Continue							

3.2.4 CAD Drawing

Computer-Aided Design (CAD) drawing encompasses the use of digital tools to create detailed and accurate visual representations of objects or systems. This process involves specialized software, such as CATIA V5, to generate technical drawings, models, and plans with precision. CAD drawings are instrumental in visualizing, analyzing, and refining designs before production begins, enabling engineers and designers to assess feasibility and optimize functionality. These drawings serve as crucial technical illustrations used in the manufacturing and assembly of structures and products, incorporating precise measurements, materials, and technical specifications. In this study, CAD drawings were produced using CATIA V5 software, exemplified by Figure 3.8, which depicts a three-dimensional model developed through this digital design process.

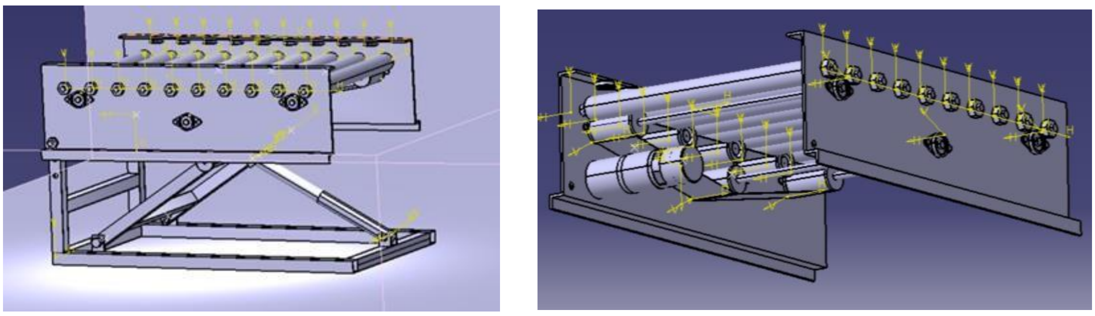


Figure 3.8: Cell to cell Conveyor in CAD drawing.

3.2.5 Fabrication

Fabrication denotes the manufacturing process whereby raw materials undergo conversion into finished components or structures through a variety of techniques. These techniques typically involve operations such as marking, cutting, drilling, and joining of materials to achieve the desired product specifications. Production methodologies within fabrication encompass practices like machining and welding, which are employed to shape and assemble components effectively. The primary objective of the fabrication process is to translate a design concept into a physical reality by meticulously selecting suitable materials, utilizing appropriate tools and machinery, and adhering strictly to defined specifications.

Fabrication plays a critical role in bringing novel concepts to fruition by enabling the development of practical prototypes, products, or frameworks that meet predetermined design criteria. Figure 3.9 illustrates the flowchart outlining the frame fabrication process for a cell-to-cell conveyor system, while Figure 3.10 depicts the flowchart detailing the body fabrication process for the same system. These visual representations serve to outline the sequential steps involved in fabricating different structural elements of the conveyor system, emphasizing the systematic approach necessary to ensure quality and precision in manufacturing.

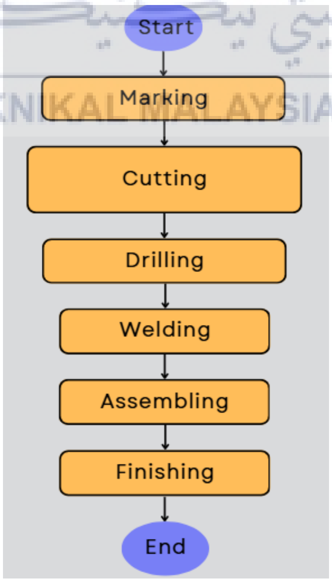


Figure 3.9: Flowchart of fabrication of frame a cell to cell conveyor system.

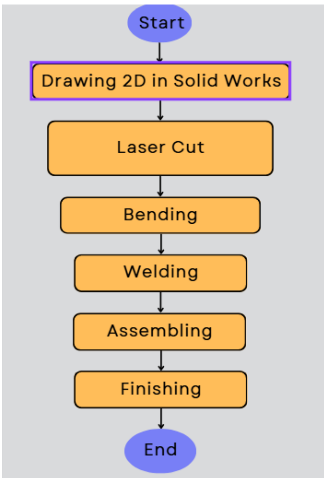


Figure 3.10: Flowchart of fabrication of body a cell to cell conveyor system.

3.2.5.1 Marking

Marking refers to the systematic process of applying discernible symbols or inscriptions onto manufactured elements or structures. This procedure involves methods such as engraving or labeling, aimed at providing essential details such as component identification numbers or cross-references to numerical measurements indicated on technical blueprints. The primary purpose of marking is to ensure traceability, facilitate accurate identification, and enable the precise assembly of manufactured components within a larger system or structure.

By labeling constituent parts, manufacturing processes can be optimized, systematized, and streamlined, thereby enhancing efficiency and effectiveness throughout construction and integration phases. The act of marking is crucial for maintaining the integrity and reliability of manufactured goods or structures, ensuring they meet specified standards and can be easily identified and tracked throughout their lifecycle.

Figure 3.11: Marking process.

3.2.5.2 Cutting

The process of cutting is a fundamental component of fabrication, integral to shaping materials by removing unwanted portions. This procedure typically involves the use of various cutting tools such as saws or grinders, chosen based on the material type and the required level of precision. Cutting is essential for transforming raw materials into specific configurations and dimensions necessary for manufacturing purposes. Precision in cutting is critical to ensure that components or structures are accurately shaped for seamless integration into larger assemblies.

Achieving precise and clean cuts during the cutting process requires meticulous planning, accurate measurements, and the application of appropriate cutting techniques. The effectiveness of the cutting process directly influences the quality and functionality of the final product. Therefore, cutting plays a pivotal role in the manufacturing process by enabling the initial shaping of materials and establishing the foundation for subsequent assembly and construction stages. This process is indispensable for ensuring that fabricated components meet exacting specifications and contribute to the overall integrity and performance of the end product.

Figure 3.12: Cutting process.

3.2.5.3 Drilling

Drilling is a fundamental production technique that employs a rotating cutting tool, known as a drill bit, to create holes in materials. This process is essential for various tasks such as assembly, fastening, or facilitating the passage of structural elements within manufactured products or structures. Drilling operations are typically performed using drilling machines or hand-held drills, depending on the material properties and the required hole specifications.

Achieving precise and clean holes during drilling necessitates careful alignment of the drill bit, appropriate drilling speed, and proper feed rate. These parameters are crucial to ensure that the drilled holes meet dimensional accuracy and surface finish requirements. Proper alignment prevents deviation and ensures that the hole is positioned exactly as specified, facilitating subsequent assembly processes or integration of components.

Drilling serves a critical function in fabrication by creating openings that accommodate fasteners, electrical wiring, piping, or other functional requirements within the product or structure. Beyond mere hole creation, drilling contributes significantly to the overall manufacturability and functionality of components by enabling efficient assembly and enhancing structural integrity. Thus, drilling stands as a pivotal process in manufacturing operations, supporting the realization of precise and functional products across diverse industrial applications.

Figure 3.13: Drilling process.

3.2.5.4 Welding

Welding is a fundamental manufacturing process that involves joining two or more parts by applying heat, pressure, or both, typically applied to materials such as metals, thermoplastics, and occasionally wood. The resulting fusion creates a joint known as a weldment, with the components being referred to as the parent materials. A filler material, also known as a consumable, is often used to enhance the strength and integrity of the weldment.

Achieving a durable and structurally sound weld requires precise alignment, ensuring a proper fit between the parts to be joined, and securing a strong connection. These factors are critical to maintaining the structural integrity of the welded assembly. Welding plays a crucial role in fabrication processes as it enables the bonding of raw materials, creating unified structures capable of withstanding high loads or pressures.

The complexity of welding necessitates thorough study and understanding, as it directly impacts the design integrity and performance of the final product. Engineers and fabricators must carefully consider welding techniques, material compatibility, joint preparation, and post-weld treatments to achieve desired mechanical properties and durability. By effectively utilizing welding processes, manufacturers can produce robust components and structures tailored to meet specific industrial applications, thus enhancing overall product reliability and functionality

Figure 3.14: Welding process.

3.2.5.5 Part Assembly

Assembly is a pivotal stage in the fabrication process, involving the integration of individual components to create a final product or structure. This process employs various methods such as riveting, screwing, or bolting to securely connect parts together. Maintaining structural integrity during assembly necessitates precise alignment, ensuring components fit together accurately, and establishing secure connections.

In fabrication, assembly holds significant importance as it consolidates multiple components into a cohesive and functional unit. By effectively joining disparate parts, assembly enables the collective system to operate as intended, achieving the required functionality and performance of the end product or structure. This requires meticulous consideration of design specifications and ensures that all assembled components interact seamlessly.

Successful assembly in fabrication involves careful planning and execution to meet engineering standards and regulatory requirements. It encompasses evaluating material compatibility, selecting appropriate fastening methods, and verifying dimensional accuracy to guarantee robust and reliable construction. Through efficient assembly practices, manufacturers achieve cohesive integration of components, thereby enhancing the overall quality and operational efficiency of fabricated products and structures.

Figure 3.15: Assembling process.

3.2.5.6 Finishing

An essential stage within the fabrication process is finishing, which encompasses applying various treatments or procedures aimed at enhancing the aesthetics, durability, and functionality of manufactured components or structures. Common finishing techniques include polishing, painting, and coating, each serving distinct purposes such as smoothing rough surfaces, protecting against corrosion or wear, and improving visual appeal.

The primary objective of finishing is to eliminate imperfections and ensure that the final product or structure meets specified requirements and standards. This stage plays a critical role in fabrication by adding the necessary final touches that enhance the overall quality and longevity of the fabricated components. By applying appropriate finishing techniques, manufacturers not only improve the durability and functionality of their products but also achieve a refined appearance that aligns with aesthetic and performance expectations.

Figure 3.16: Finishing process.

3.2.5.7 Bending

Sheet metal bending is a pivotal metal forming process utilized extensively in manufacturing to transform flat sheets of metal into three-dimensional shapes, angles, or curved configurations. This technique is indispensable for producing a diverse range of metal components and products, especially those requiring precise edge finishes, enhanced structural rigidity, or complex geometric profiles.

The process of sheet metal bending is predominantly executed using specialized equipment such as press brakes or custom press tooling. These tools exert force on the metal sheet, inducing deformation to achieve the desired shape or angle. Press brakes, for instance, apply controlled pressure to bend the metal along a predetermined axis, enabling precise manipulation of the sheet metal into various configurations.

Figure 3.17: Bending process.

3.2.5.8 Drawing 2D

A 2D drawing serves as a detailed depiction of a product, providing essential dimensional information through a graphical representation. This drawing is a critical preparatory step, particularly in contexts where subsequent manufacturing processes, such as laser cutting, are involved. Laser cutting operations typically rely on 2D drawings generated using software platforms like AutoCAD and SolidWorks.

The primary function of a 2D drawing is to communicate precise dimensions, geometries, and specifications of a component or product. These drawings serve as the blueprint for laser cutting operations by providing essential data that guides the creation of cutting paths and outlines. In practical terms, the 2D drawing serves as the basis for generating G-code, a machine-readable programming language used to control laser cutting equipment.

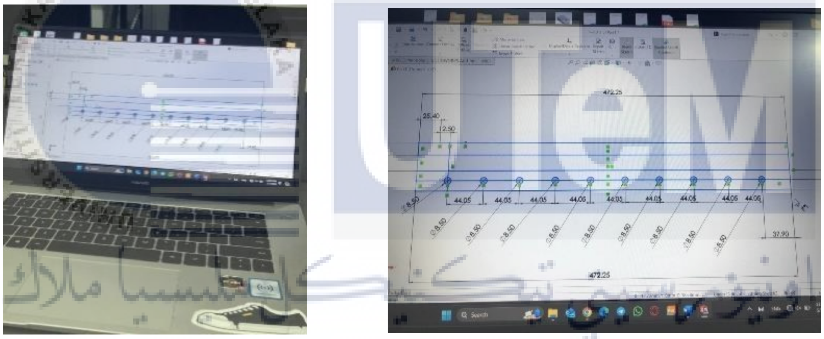


Figure 3.18: Drawing 2D process.

3.2.5.9 Laser Cut

A laser cutter operates through the precise guidance of a high-energy, narrow light beam directed vertically onto a sheet or plate of material. This focused beam traverses the material in the X and Y directions across the machine bed, cutting it into a two-dimensional profile. The cutting path and pattern are dictated by computer-generated instructions known as G-code.

During operation, the laser beam heats the material to the point of melting or burning, depending on the material type and thickness. In some instances, a high-pressure gas stream is employed to expel molten material from the cutting area. This gas stream ensures that the molten residue is removed promptly, preventing it from interfering with subsequent cutting passes and enabling cleaner cuts.

Alternatively, for certain materials, the laser beam vaporizes the material directly, bypassing the molten state. This vaporization process yields precise cuts with minimal thermal impact on the surrounding material, maintaining structural integrity and reducing the need for post-processing.

Figure 3.19: Laser Cut process.

3.2.6 Bill Of Material

A Bill of Materials (BOM) serves as a comprehensive document that meticulously lists all the components, materials, and supplies essential for the construction or completion of a product or project. This document plays a critical role as a detailed reference and inventory management tool throughout the stages of production, assembly, and procurement. Typically, a BOM includes detailed information such as part numbers, descriptions, quantities required, and sometimes cost projections for each item listed.

The primary function of a BOM is to facilitate precise and efficient sourcing, ordering, and tracking of materials needed for manufacturing. It enables project managers and stakeholders to plan resources effectively, allocate budgets, and coordinate activities related to production. By providing a clear and structured overview of necessary components, the BOM enhances the efficiency of the manufacturing process and promotes collaboration among team members and external suppliers.

In the context of developing a passive exoskeleton prototype, Table 3.11 illustrates the components list specified in the BOM, outlining the essential parts and materials required to fabricate the prototype. This ensures that all necessary elements are accounted for and readily available, supporting the systematic and organized execution of the project's manufacturing and assembly phases.

Table 3.11: Bill of materials.

Part No.	Part Name	Quality	Cost per Units (RM)	Cost (RM)
1	Electric Jack	1	140	140.00
2	Speed Controller	1	20.00	20.00
3	Converter Ac to Dc	1	12.00	12.00
4	Motor Dc (248 Watt)	1	265.00	265.00
5	Socket Plus	1	3.00	3.00
6	Wire 25mm	1	10.00	10.00
7	Wire 1.5mm	1	4.00	4.00
8	Rod Stainless steel shaft 1m	2	15.00	30.00
9	Heat Shrink Tube 30 mm	1	3.40	3.40
10	Heat Shrink Tube 25 mm	10	2.80	28.00
11	Heat Shrink Tube 5 mm	1	3.50	3.50
12	Heat Shrink Tube 3 mm	1	2.90	2.90
13	Conveyor roller	10	25.03	250.30
14	Double bearing Driving wheel	6	27.20	163.2
15	Sliding shower roller	20	0.31	6.25
16	Chain Link connection	1	2.04	2.04
17	Chain 144 links	1	14.22	14.22
18	Thrust bearing bore	6	1.49	8.94

19	Chain gear	2	9.50	19.00
20	Shower door roller	2	2.48	4.96
21	Screw 8mm	4	0.80	3.20
22	Screw 5mm	39	0.50	19.50
23	Nut 5mm	39	0.10	3.90
24	Nut 8mm	22	0.40	8.80
25	Mild Steel Hollow	1	10.03	10.03
26	Gi Plate	2	45.4	91.67
			Total	1127.81

3.3 Evaluate the Functionality and Usability of the Developed Cell to cell Conveyor Prototype

Any project's success depends on two critical components: functionality and usability. Functionality is the capacity of a system or product to successfully carry out its intended functions. It emphasizes functions, capacities, and efficiency. On the other hand, usability refers to how quickly and easily users can interact with a product or system to accomplish their objectives. User experience, logical design, and satisfaction are highlighted. Functionality ensures that the project satisfies its functional requirements, while usability guarantees that users can easily navigate, comprehend, and make use of the project. A valuable and user-friendly final product must take into account both functionality and usability. Figure 3.20 shows the evaluation of functionality and usability of the developed Cell to cell conveyor prototype.

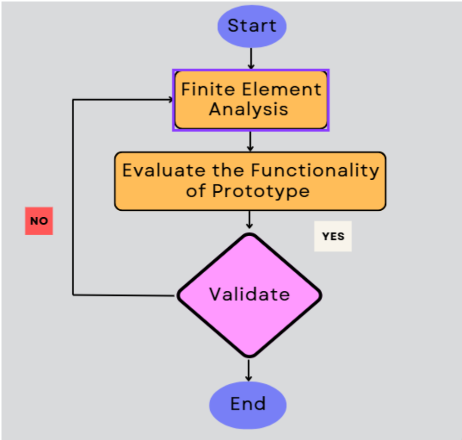


Figure 3.20: Flowchart of evaluate the functionality and usability of cell to cell conveyor

3.3.1 Finite Element Analysis of the Cell to cell conveyor system

Performing stress analysis is a critical procedure aimed at evaluating the strength and performance of a structure or component under various loading conditions. In the context of the prototype designed using Catia V5, this analysis is conducted using Ansys software, which employs mathematical and computational tools to assess internal forces, deformations, and stresses within the item. By examining these parameters, stress analysis helps identify areas of potential high stress or failure, thereby guiding informed design decisions.

The primary objectives of stress analysis include determining the suitability of materials, validating design specifications, and ensuring the safety and reliability of the final product. This process is instrumental in optimizing structural design and mitigating the risk of mechanical failures. By providing insights into how a prototype will respond to different operational conditions, stress analysis aids in refining designs to enhance performance and durability.

Figure 3.21 presents the outcomes of the stress analysis conducted on the prototype's structure, illustrating visual representations of stress distributions and critical points. This analysis serves as a pivotal step in the iterative design process, where adjustments can be made based on the insights gained to enhance the overall integrity and functionality of the prototype.

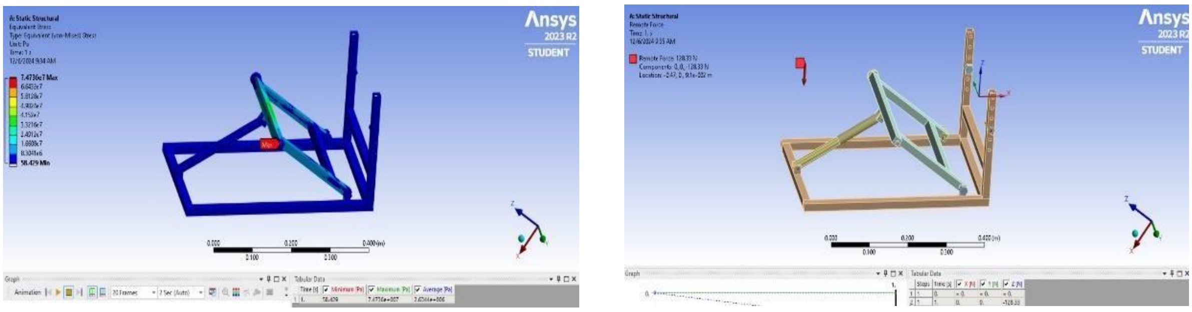


Figure 3.21: Stress analysis of conveyor frame.

3.3.2 Methodology for assessment Revolution Per Minute Testing

Revolutions Per Minute (RPM) represents a fundamental metric within the manufacturing industry, quantifying the rotational speed of machines or tools in terms of the number of complete rotations they execute per minute. This metric holds significant importance as it directly influences the efficiency, productivity, and operational dynamics of manufacturing processes.

The primary purpose of utilizing machine RPM is to optimize manufacturing processes by precisely controlling and monitoring the speed at which machinery operates. By measuring RPM, engineers and operators can assess whether machines are functioning within their optimal speed ranges. This evaluation is crucial for identifying and maximizing the machine's capabilities, both at maximum and minimum operational capacities.

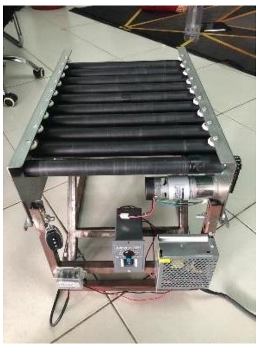
The experimental methodology employed for RPM measurement typically involves the application of a tachometer, a specialized device used specifically for this purpose. The tachometer provides accurate readings of RPM by detecting and calculating the rotational speed of machine components such as shafts, motors, or other rotating parts. Figure 3.19 serves as a visual depiction illustrating the configuration and appearance of the tachometer equipment utilized in these tests. This visual representation aids in comprehending the setup and instrumentation essential for conducting RPM measurements, highlighting the technical precision required for evaluating machine speed effectively

.

In essence, RPM measurement and analysis play a critical role in industrial settings by facilitating informed decisions regarding machinery performance, ensuring optimal operational conditions, and ultimately contributing to enhanced productivity and efficiency in manufacturing processes.

Figure 3.22: Tachometer equipment.

Table 3.12: Prosedure for the operation of the Tachometer (Rpm) equipment.

Steps	**Description**	**Pictures**
1	Switch on the Tachometer	
2	Stick a white sticker on the roller conveyor	
3	Switch on the conveyor	

4	Set the minimum or maximum speed of conveyor on speed control	
5	Set the angle betweet 0° to 25° of conveyor using rotary protractor measuring	 
6	Place the load between 5Kg to 14Kg on the conveyor	
7	Point the Tachometer on the surface of the white sticker	

8	The Tachometer reading will be presented.	

3.3.3 Methodology for assessment Current Testing

In the realm of engineering, a current test denotes a systematic procedure designed to measure and analyze the electric current traversing a circuit, component, or device. The primary objective of conducting such a test is to evaluate critical electrical characteristics pertaining to current consumption, operational performance, efficiency, and safety under varying operational conditions, encompassing both maximum and minimum capacities of the equipment under scrutiny.

The experimental setup for a current test typically involves the utilization of specialized instrumentation such as an ammeter, which is specifically employed to quantify the magnitude of electrical current flowing through the circuit or device being evaluated. This instrument is essential for precise measurement and monitoring of current levels, ensuring accurate assessment of electrical behavior and performance characteristics.

Figure 3.23 serves as a visual representation illustrating the ammeter equipment employed in these tests. This depiction aids in understanding the configuration and setup utilized for conducting current measurements, highlighting the instrumental role of the ammeter in facilitating comprehensive analysis and evaluation of electrical systems.

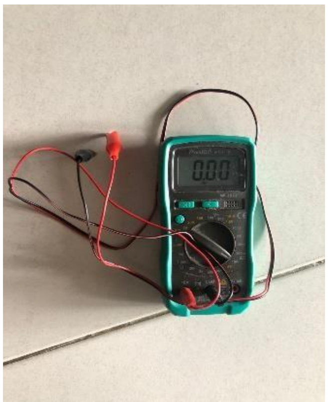
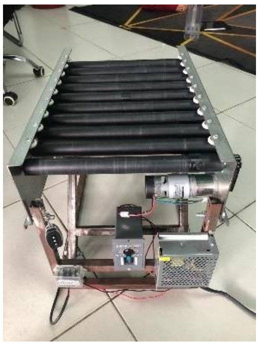
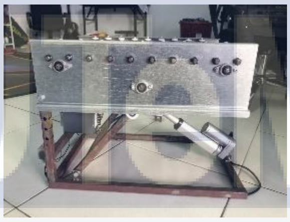
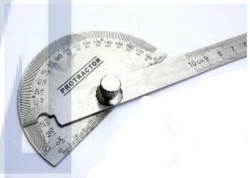


Figure 3.23: Ammeter equipment.

Table 3.13: Prosedure for the operation of the Ammeter equipment.

Steps	Description	Pictures
1	Switch on the Ammeter	
2	Connect the Ammeter in parallel on the Dc+ and Dc- wires of the conveyor motor	

3	Switch on the conveyor	
4	Set the minimum or maximum speed of conveyor on speed control	
5	Set the angle betweet 0° to 25° of conveyor using rotary protractor measuring	 
6	Place the load between 5Kg to 14Kg on the conveyor	
7	The Ammeter reading will be presented.	

3.4 Summary of the Methodology

The design and development of a cell to cell conveyor system involves a systematic approach aimed at optimizing the functionality and performance of its conveyor. This methodical process encompasses concept development, mechanical design, prototype fabrication, and rigorous testing phases. Key objectives include comprehending design specifications, assessing current conveyor specifications, and selecting appropriate materials and components to meet desired performance criteria.

Upon completion of the prototype, extensive testing is conducted to evaluate its efficiency, comfort, and usability in real-world applications. This structured methodology ensures the systematic creation of a cell to cell conveyor that is not only practical but also highly effective in enhancing operational capabilities.

Table 3.14 illustrates the correlation between the outlined methodology and the objectives of the study, providing a visual representation of how each stage contributes to achieving the overall goal of developing an optimized cell to cell conveyor system. This approach emphasizes precision in design, robustness in development, and comprehensive evaluation through testing, thereby facilitating the creation of a functional and reliable industrial solution..

Table 3.14: The relationship between objectives and methodology of the study.

Objectives	**Methodology**
To determine design requirement of the cell-to-cell conveyor system.	• Information from market conveyor • Performing Benchmarking • House of Quality
To design and develop of cell to cell conveyor system.	• Conceptual Sketching • Concept Screening • Concept Scoring • CAD Drawing • Fabrication of prototype
To analyze the functionality and applicability of cells to cell conveyor systems.	• Stress Analysis • Functionality of the prototype • Combined Data Analysis

CHAPTER 4

RESULTS AND DISCUSSION

This chapter elucidates the outcomes and discussion stemming from the development of a prototype cell-to-cell conveyor system tailored for the parcel industry. Central to achieving its primary objective of addressing the requirements for efficiently transporting goods between locations, the study conducted a thorough survey to identify pertinent design specifications. The results of this investigation are detailed herein, offering insights into the design considerations and development processes involved.

Additionally, this section explores the evaluation of the conveyor system's impact on electric current and speed, underscoring its design enhancements aimed at optimizing performance during the transportation of goods under varying inclinations and loads. The discussion encompasses the integration of design features to enhance operational efficiency and accommodate diverse operational conditions encountered in parcel handling scenarios.

4.1 Design Requirements to Fabricate a Cell to Cell Conveyor system.

The development of a prototype for a cell-to-cell conveyor system aimed at supporting the parcel industry's delivery demands entails meticulous attention to a diverse array of design requirements essential for achieving its objectives. Table 4.1 consolidates these critical design specifications into key components that must be carefully considered during the prototype's fabrication. Emphasizing aspects such as material selection, physical geometry, performance characteristics, user requirements, and environmental considerations, the table serves as a comprehensive guide to ensure the prototype aligns with the operational and functional expectations of the parcel delivery environment. This structured approach facilitates the systematic integration of essential features and parameters necessary to optimize the conveyor system's efficiency and effectiveness in meeting industry demands.

Table 4.1: Design requirements of passive exoskeleton prototype

Design Requirements	**Specifications**	**Justification**
Physical dimension/ geometry	<u>Frame:</u> ➢ Length: 49 cm ➢ Width: 30 cm ➢ High: 24 cm <u>Conveyor:</u> ➢ Operating angle: Adjustable angle, maximum to 25° ➢ Length: 46 cm ➢ Width: 35 cm ➢ Thickness: 15 cm	To ensure the conveyor is medium-sized design and stable. Adapted geometry enables seamless integration with the user, facilitates angular movement and minimizes space consumption.
Performance characteristic	<u>Maximum sustained load:</u> ➢ 13 kg Type of Motion: ➢ Linear <u>Range of Motion:</u> ➢ 0° to 25°	These features directly impact the conveyor's ability to provide effective support on the load imposed during the activity, accommodating the movement of the load and maintaining the load without deformation
Materials	➢ GI Plate ➢ Mild Steel ➢ Aluminium ➢ Stainless steel ➢ Nylon	Mild steel affordable and strong. This material can withstand a load of up to 20 tons and is earthquake resistant. GI plate Stainless steel is a strong, resistance to corrosion and high life expectancy. The aluminium is lightweight and strong, providing necessary support without hindering mobility. nylon is safe

		supports the part between the frame and the conveyor while allowing for flexibility.
Environmental requirements	➢ Resistance to corrosion ➢ Material Recyclability ➢ Wear and Tear	These considerations ensure the device remains durable and reliable across different environments while adhering to sustainable practices. The incorporation of these features results in an environmentally friendly, long lasting solution tailored to individual needs, promoting enhanced mobility and an improved overall quality of life.

4.1.1 House of Quality of Cell to Cell Conveyor System.

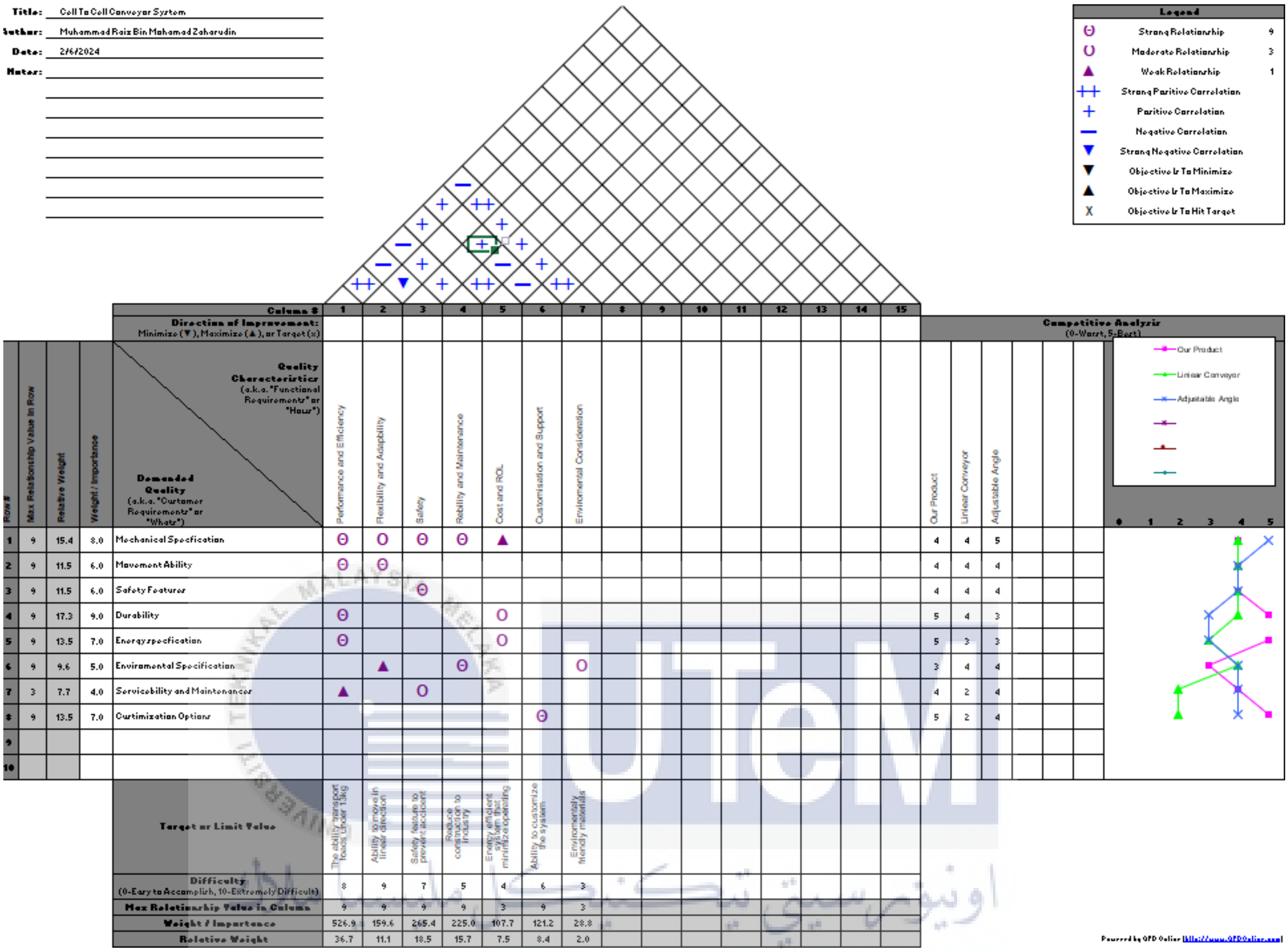


Figure 4.1: House of Quality

The House of Quality (HOQ) serves as a crucial tool bridging user requirements with the formulation of functional specifications for the cell to cell conveyor design. These preferences are systematically converted into specific functional requirements, encompassing critical elements such as Performance and Efficiency, Flexibility and Adaptability, Safety, Reliability and Maintenance, Cost and Return on Investment (ROI), Customization and Support, and Environmental considerations, as illustrated in the table in Figure 4.1. Within this matrix, significant emphasis is placed on technical specifications, particularly focusing on ensuring performance and efficiency, which highlights users' primary concerns regarding mechanical specifications, movement capabilities, durability, and energy efficiency. Subsequently, attention is directed towards safety features, underscoring the importance of mechanical specifications in ensuring safety. These insights derived from the HOQ provide invaluable guidance, directing the development process to prioritize aspects critical for user satisfaction and the effective functionality of the cell to cell conveyor.

4.1.2 Technical Specifications of Cell to Cell Conveyor System.

The technical specifications of a product play a pivotal role in assessing its efficiency, operational capabilities, and suitability for its intended application. Tables 4.2 and 4.3 offer a detailed analysis of the technical specifications pertaining to the cell-to-cell conveyor prototype. These tables provide valuable insights into the system's capabilities and potential advantages, highlighting key parameters such as operational speed, load capacity, power requirements, dimensional characteristics, maximum torque capacity and specialized features relevant to its function in the industry. By delineating these specifications, the tables serve as a comprehensive reference for evaluating the performance and functionality of the conveyor prototype, thereby supporting informed decision-making during its development and deployment phases.

Table 4.2: Technical Specifications for cell to cell conveyor system.

No.	Product Specification	Technical Specification
1	Flexibility and Adaptability	Movement Ability
2	Safety and Ergonomics	Safety Features
3	Reliability and Maintenances	Construction and Durability
4	Customization and Support	Environmental Specifications
5	Environmental and Considerations	Maintenance and Serviceability
6	Cost and Return of Investment	Power and Energy Specifications
7	Performance and Efficiency	Mechanical Specifications

Table 4.3: Technical Specifications for cell to cell conveyor system.

Items	Specifications
Dimensions (mm)	
Overall height	360
Overall length	470
Overall width	345
Weight (kg)	
Cell to cell conveyor	7.94
Operating speed (Rpm)	
Ability	46 to 246
Operating angle (°)	
Inclination angle	0 to 25
Motor’s torque (N.m)	
Maximum ability	150

The provided specifications outline the dimensions and capabilities of a cell-to-cell transmitter system. The transmitter system possesses a physical profile characterized by an overall height of 360 mm, a reach length extending to 470 mm, and a width spanning 345 mm. With a total weight measuring 7.94 kg, the system is engineered to support a broad range of goods movement speeds, ranging from 46 rpm to 246 rpm. This variability in rotational speed accommodates diverse operational requirements, enhancing its versatility in industrial applications.

Furthermore, the transmitter features an adjustable tilt angle capability ranging from 0 to 25 degrees. This adjustable inclination capability enables the conveyor system to adapt to varying inclinations, thereby facilitating the transport of goods at different heights as necessitated by operational conditions.

Moreover, the selection of motors emphasizes durability and robust torque capabilities suitable for industrial parcel transportation tasks. Specifically, the motors are designed to deliver a maximum torque capacity of 150 N·m, ensuring reliable performance under demanding operational scenarios.

These specifications collectively underscore the system's suitability for industrial applications requiring efficient and adaptable conveyor solutions capable of handling diverse operational demands with precision and reliability.

4.2 Design and Develop a Cell to cell Conveyor System.

This section elaborates on the design specifications for the cell to cell conveyor prototype and presents various design concepts for consideration. The process entails identifying the optimal concept, which is then translated into a visual representation using CATIA software.

4.2.1 Conceptual Design

Several designs have been produced during the concept design phase in accordance with various collected criteria. Derived from a thorough analysis of design prerequisites and technical specifications, a series of five conceptual designs, denoted alphabetically as A, B, C, D, and E, has been devised. In each design concept, a distinct set of features and innovations has been implemented to effectively address identified technical priorities and specifications.

Table 4.4: Product conceptual design.

Concept	Design	Description
A		This conceptentails the utilization of rollers affixed to the conveyor surface to facilitate the movement of transported goods.
B		This concept involves the implementation of belts on conveyors, which interact with roller mechanisms to facilitate the movement of goods. The

		integration of belts with roller conveyors aims to enhance the efficiency and effectiveness of the conveyor system's operation.
C		This concept pertains to the conveyor's ability to transport goods at varying angles, facilitating movement both horizontally and vertically. The objective is to enable the conveyor to transport goods efficiently across different elevations, thereby enhancing its operational versatility and utilization.
D		This idea describes a conveyor using a belt to move the roller conveyor. This can improve conveyor performance. Next, use a jack to adjust the angle on the conveyor. The primary objective is to facilitate the movement of goods to specified higher locations, thereby enhancing the overall efficiency and utilization of the conveyor system.
E		This concept entails the adjustable inclination of the conveyor system, allowing it to transport goods at different angles, including elevated

		positions as required. The primary objective is to facilitate the movement of goods to specified higher locations, thereby enhancing the overall efficiency and utilization of the conveyor system.

4.2.2 Concept Screening

Table 4.5: Concept screening

Selection criteria	Concept A	Concept B	Concept C	Concept D	Concept E
Flexibility and Adaptability	+	+	-	-	+
Safety	-	+	+	+	-
Customization and Support	-	-	-	+	+
Performance and Efficiency	+	-	-	+	+
Reliability and Maintenance	-	-	+	-	+
Sum '+' s	2	2	2	3	4
Sum '-' s	3	3	3	2	1
Total	-1	-1	-1	1	3
Rank	5	5	5	2	1
Continue	NO	NO	NO	YES	YES

4.2.3 Concept Scoring

Based on the outcomes of the concept screening outlined in Table 4.6, the two leading concepts that achieved the highest rankings in the screening process advanced to the subsequent phase of concept scoring. The objective of this stage was to determine the most effective concept among the selected pair. Through the assignment of weighted scores based on predefined criteria, the concept securing the highest rank would be identified as the preferred idea for integration into the developmental phase of the cell-to-cell conveyor system. This systematic approach ensures that the chosen concept aligns closely with the established design requirements and offers optimal solutions to enhance the conveyor system's functionality and performance.

Table 4.6: Concept scoring

EvaluationCriteria	Weight (%)	Concept D		Concept E	
		Ranking (1-5)	Weight score	Ranking (1-5)	Weight score
Flexibility and Adaptability	10	5	0.5	2	0.2
Safety	13	2	0.26	5	0.65
Customization and Support	28	5	1.4	2	0.56
Performance and Efficiency	34	5	1.7	4	1.36
Reliability and Maintenance	15	4	0.6	5	0.75
Total Score		4.46		3.52	
Rank		1		2	
Continue		YES		NO	

In the realm of concept scoring, Concept D has emerged as the preferred choice, achieving the highest total score of 4.46, while Concept E attained the lowest total score of 3.52. The selection of Concept D is grounded in its strong alignment with the defined evaluation criteria, demonstrating a clear adherence to established standards. This decision reflects a meticulous evaluation of each concept's attributes, where Concept D distinguishes itself by displaying superior performance across various dimensions.

The concept scoring process, integral to the development of a Cell to Cell Conveyor System, is complex and influenced by several factors. Primary among these factors are the predefined evaluation criteria, serving as crucial benchmarks against which each conceptual framework is rigorously assessed. These criteria encompass aspects such as functionality, durability, usability, and considerations pertaining to user needs, collectively forming a comprehensive framework for evaluating the efficacy of each concept. Therefore, an exhaustive and multifaceted approach to concept scoring is essential to gain nuanced insights into the suitability of each concept for advancing the development of a Cell to Cell Conveyor System.

4.2.4 Develop Design of Cell to Cell Conveyor Prototype

This section provides an in-depth exploration of the design specifications for the cell-to-cell conveyor system, presenting several design concepts for evaluation and consideration. The process involves the critical step of identifying the optimal concept, which is subsequently translated into a visual representation using advanced engineering design software, such as CATIA. This software facilitates the detailed modeling and simulation necessary to refine and finalize the conceptual designs before proceeding to prototype development and testing phases.

4.2.4.1 Bill of Materials (BOM)

A prototype of a cell-to-cell conveyor has been developed in strict adherence to the specified requirements of end-users. The initial conceptual design phase facilitated a thorough examination of the technical aspects of the design, offering prompt responses and exploring potential solutions to address constraints, opportunities, and considerations related to framework and construction methods. This preliminary phase precedes the finalization of the product for practical end-user implementation. The conceptual details of the cell-to-cell conveyor prototype are outlined comprehensively in Table 4.7.

Table 4.7: Bill of Materials for the cell to cell conveyor prototype.

No.	Component	Quantity	Description
1	 Electric Jack	1	Aluminium (320mm x 40mm) Provide support and push force for conveyor angle changes
2	 Speed Controller	1	Polimer (60mm x 100mm x 90mm) Control and adjust the speed of the conveyor motor
3	 Converter Ac to Dc	1	Aluminium (95 mm x 40 mm x 130 mm) Controlling and changing Alternating Current to Direct Current
4	 Motor Dc (248 Watt)	1	Aluminium (40 mm x 150 mm) Fundamental electromechanical to convert electrical energy into mechanical energy
5	 Socket Plug	1	Copper and Polimer (450 mm x 450 mm x 20 mm) To provide a connection point for electrical appliances and devices to receive power from a building's electrical system

6	 Wire 25mm	1	Rubber and copper (25 mm x 1000 mm) Fundamental component for transmitting electrical signals or power from one point to another.
7	 Wire 1.5mm	1	Rubber and copper (1.5 mm x 2000 mm) Fundamental component for transmitting electrical signals or power from one point to another
8	 Rod Stainless steel shaft 1m	2	Stainless Steel (8 mm x 1000 mm) To hold the conveyor wall and hold the driving wheel
9	 Heat Shrink Tube 30 mm	1	Rubber (30 mm x 50 mm) To cover and protect the surface of the driving wheel
10	 Heat Shrink Tube 25 mm	10	Rubber (25 mm x 10000 mm) To cover and protect the surface of the conveyor roller
11		1	Rubber (5 mm x 2000 mm) To cover and protect the surface of the wire

	Heat Shrink Tube 5 mm		
12	 Heat Shrink Tube 3 mm	1	Rubber (3 mm x 2000 mm) To cover and protect the surface of the wire
13	 Conveyor roller	10	Stainless Steel (25 mm x 340 mm) Facilitate the movement of goods or materials along a conveyor and platform
14	 Double bearing Driving wheel	6	Aluminium (50 mmx 30 mm) Driving and hold the conveyor belt
15	 Sliding shower roller	20	Aluminium and Nylon (25mm x 6 mm) Diffuse and reduce the friction of goods against the conveyor wall
16	 Chain Link connection	1	Mild Steel (5 mm x 11 mm x 10 mm) Merge the conveyor chain
17	 Chain 144 links	1	Mild Steel (5 mm x 10 mm x 200 mm) A chain is used to transmit mechanical power to move the cooveyor

18	 Thrust bearing bore	6	Stainless Steel and Aluminium (50 mm x 30 mm x 45 mm) Holding and giving rotation to the shaft
19	 Chain gear	2	Mild Steel (20 mm x 20 mm) To transmit torque between shafts and convert to speed
20	 Shower door roller	2	Aluminium and Nylon (30 mm x 6 mm) Holding the frame, at the same time absorbing and reducing the force between the conveyor body and the frame.
21	 Screw 8mm	4	Mild Steel (8 mm x 45 mm) to fasten and secure components of the conveyor
22	 Screw 5mm	39	Mild Steel (5 mm x 25 mm) to fasten and secure components of the conveyor
23	 Nut 5mm	39	Mild Steel (9 mm x 5 mm) Secures the bolt in place, ensuring the stability of the connected components.

24	 Nut 8mm	22	Mild Steel (10 mm x 6 mm) Secures the bolt in place, ensuring the stability of the connected components.
25	 Mild Steel Hollow	1	Mild Steel (19 mm x 19 mm x 15000) To a skeleton that provides support, stability, and rigidity to body conveyor.
26	 Aluminium Plate	2	Aluminium Plate (609 mm x 2 mm x 862 mm) Used as a conveyor wall that holds the conveyor roller

4.2.4.2 Design of Full Assembly View

Figure 4.2 offers a comprehensive depiction of the assembled prototype. This section visually outlines the integration of various components, including the supporting frame and primary conveyor. The cell-to-cell conveyor system has emerged as a pivotal solution for transporting items within the industry, facilitating efficient movement from one location to another.

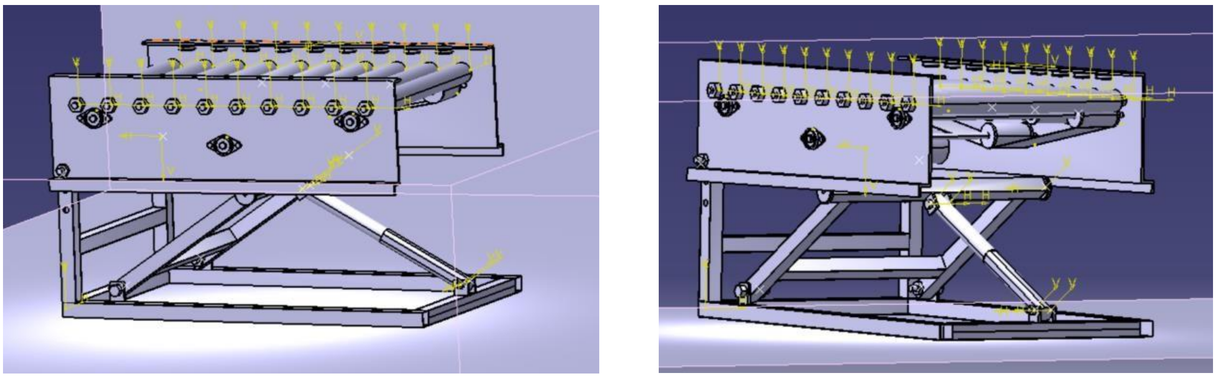


Figure 4.2: Full assembly of prototype

Based on the comprehensive assembly view, enhancements to the design of the cell-to-cell conveyor prototype can be achieved by integrating insights gained from a holistic installation perspective. This approach elucidates the positioning of the prototype on the lower limb of the user, preparing it for practical implementation.

4.2.4.3 Design of Isometric View

An isometric view functions as a three-dimensional representation of the cell-to-cell conveyor prototype, where all dimensions undergo equal scaling to maintain parallel lines and ensure consistent size relationships. Unlike authentic perspective illustrations, isometric views incorporate angles of 120 degrees between axes, contributing to a visually balanced portrayal.

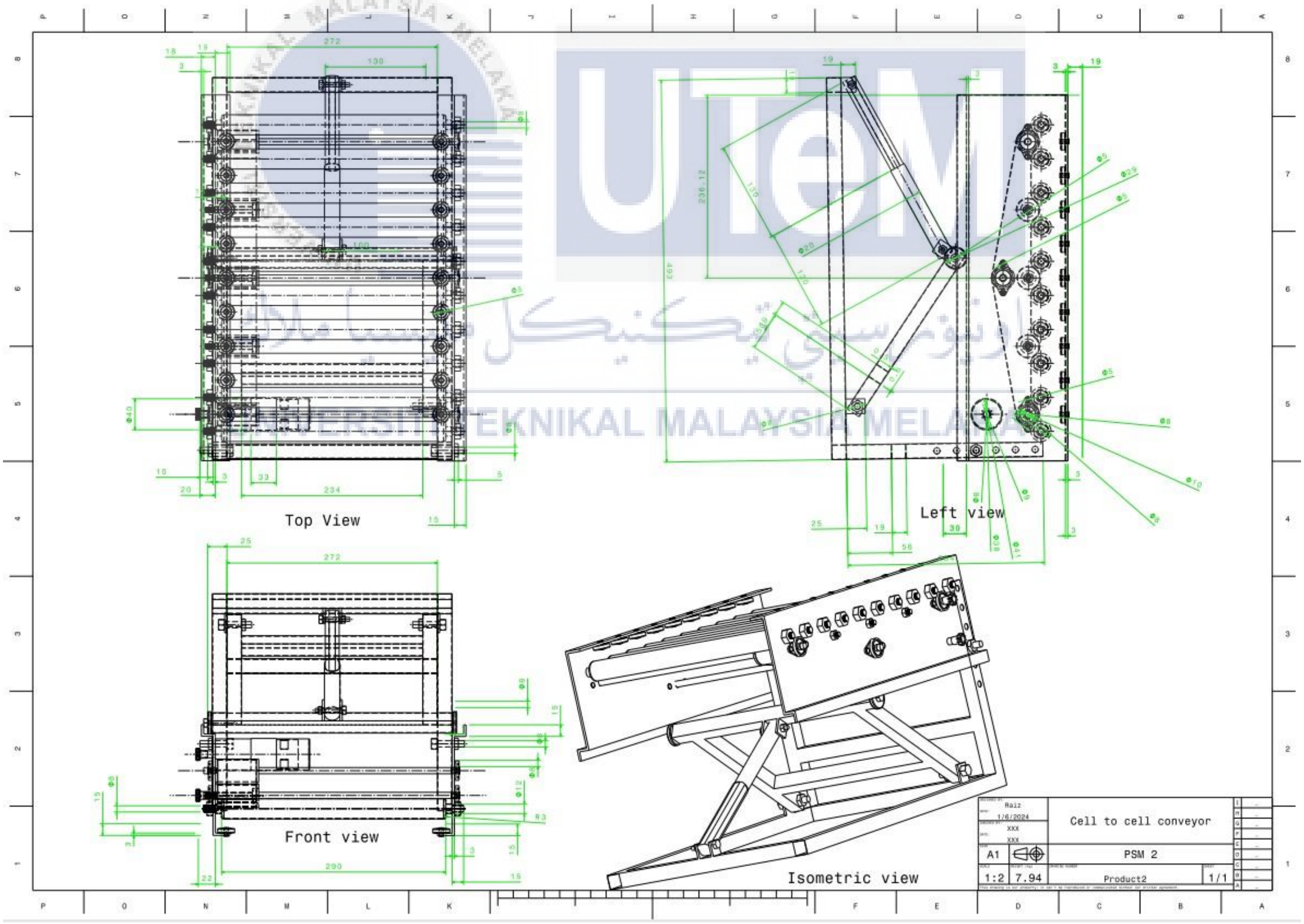


Figure 4.3: Isometric view of cell to cell conveyor prototype

Creating an isometric drawing for the cell-to-cell conveyor prototype represents a crucial phase in the design process. This step ensures accuracy in dimensions, validates the design concept, and provides manufacturing guidance through a detailed visual representation, as depicted in Figure 4.3. By generating an isometric drawing, improvements and refinements were implemented in the design of the cell-to-cell conveyor prototype. This process ultimately led to the development of a product that meets criteria related to functionality, aesthetics, and manufacturability.

4.2.4.4 Design of Exploded View

During the development phase of a cell-to-cell conveyor prototype, an exploded view serves as a visual representation depicting individual components separated from each other. This illustration is instrumental in identifying each part distinctly, showcasing the precise assembly sequence, and enhancing understanding of how components interact with one another. The detailed view plays a crucial role in refining the prototype, ensuring dimensional accuracy, and facilitating clear communication throughout the manufacturing process.

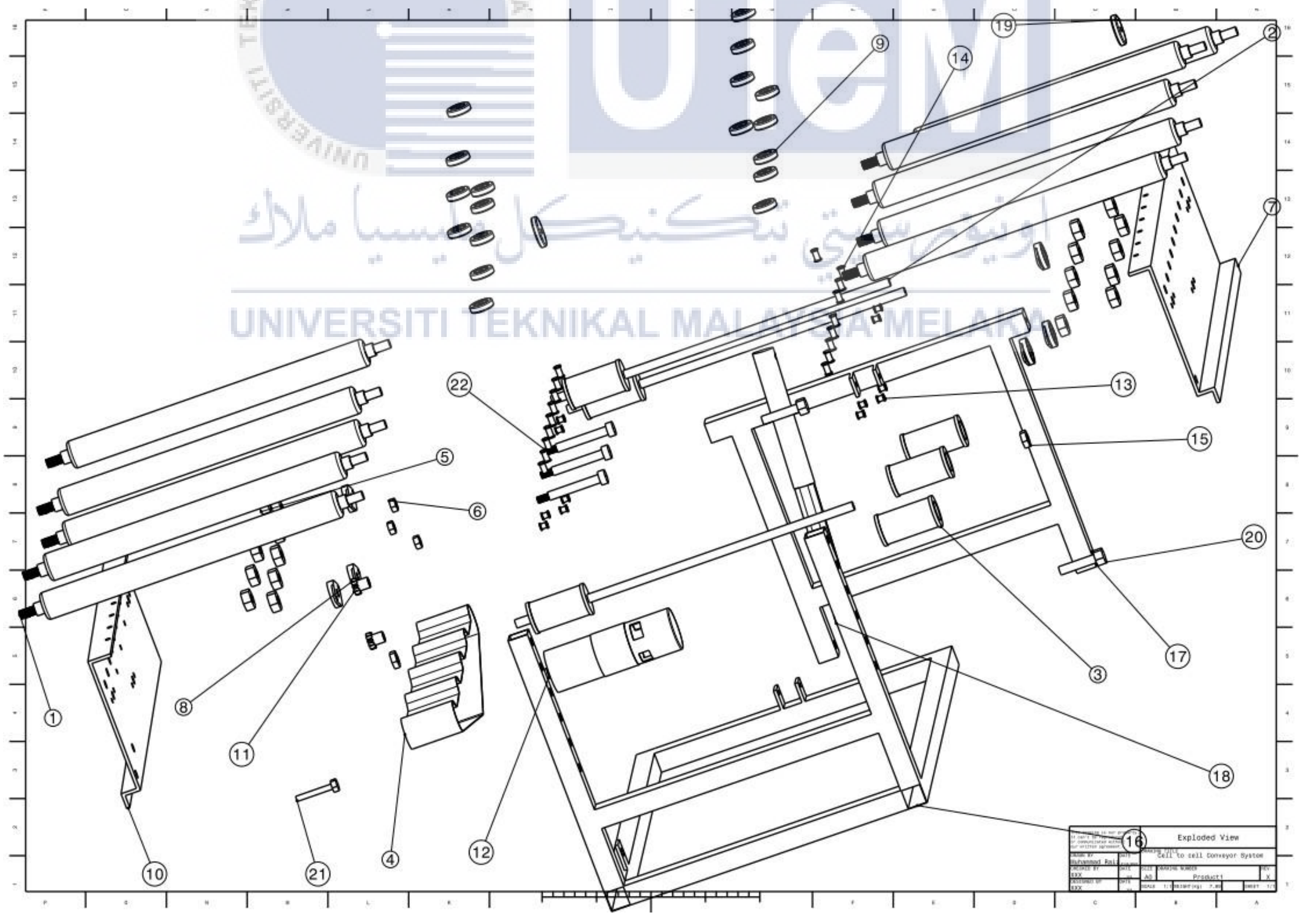


Figure 4.4: Exploded view of cell to cell conveyor prototype

Figure 4.4 depicts the exploded view of the passive exoskeleton prototype, where its components are presented separately to illustrate their individual functionalities and interconnections.

4.2.4.5 Circuit Diagram

In the process of developing prototypes for cell-to-cell transmitters, a circuit diagram, also referred to as a schematic or electrical diagram, serves as a graphical representation of an electrical circuit. It employs universally recognized symbols to depict the components comprising the circuit and their interconnections. Essential components typically illustrated in a circuit diagram encompass various electronic elements like resistors, capacitors, transistors, diodes, and integrated circuits (ICs).

Fundamental aspects featured in a circuit diagram include:

1. Components: Represented by standardized symbols that visually denote different electrical and electronic elements integrated into the circuit design.
2. Connections: Lines or wires illustrate how components are electrically linked within the circuit, indicating the path of electrical current flow.
3. Power Source: Symbols denote sources of electrical power, such as batteries or AC adapters, essential for powering the circuit's operation.
4. Ground: A grounding symbol signifies the reference point for voltage measurements and ensures electrical stability by connecting components to a common ground potential.
5. Labels and Annotations: Additional information, such as component values, ratings, and specific operational instructions, may be included to provide clarity and guidance for assembly and operation.

Circuit diagrams, exemplified by Figure 4.5, are indispensable tools in electrical engineering and related disciplines. They facilitate comprehension and manipulation of intricate electrical systems by offering a standardized and concise visual representation. This aids engineers and technicians in various tasks, including initial circuit design, performance analysis, troubleshooting, and documentation of circuit configurations.

Overall, circuit diagrams play a pivotal role in advancing the development of electronic devices and systems, ensuring accurate communication of design concepts and operational parameters across engineering teams and stakeholders involved in the project.

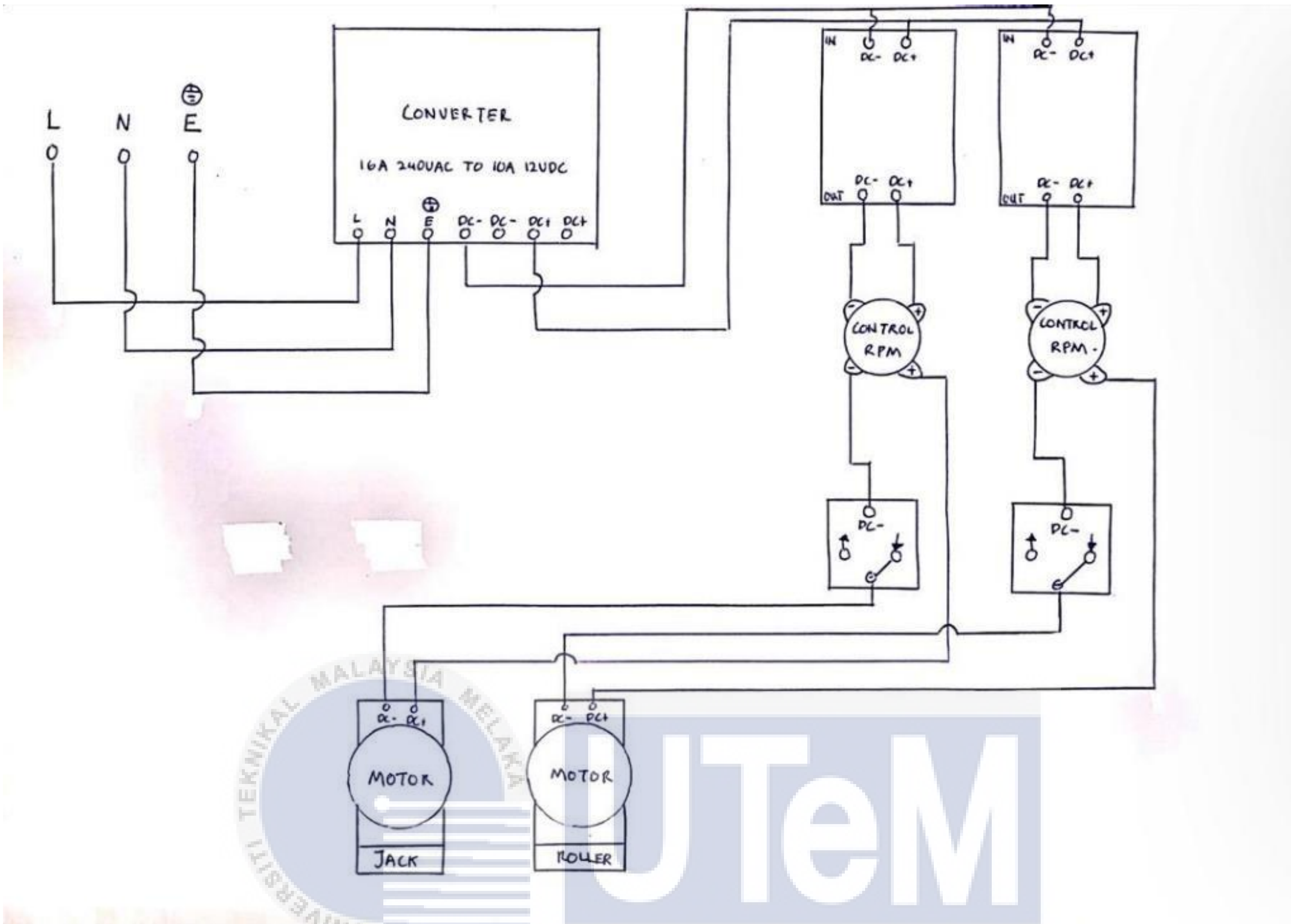


Figure 4.5: Circuit Diagram

4.2.5 Develop Finite Element Analysis

The static structural analysis of the cell-to-cell conveyor prototype through finite element analysis entails a detailed assessment of its mechanical behavior when subjected to a distributed load of 128.33 N, which represents a critical force acting on the conveyor surface. This numerical investigation utilizes the finite element method (FEM) to anticipate the distribution of stresses, offering crucial insights into the structural integrity and performance of the conveyor system. The FEM approach enables precise modeling of complex geometries and loading conditions, facilitating accurate predictions of stress concentrations and deformation patterns within the conveyor structure. Such analyses are essential for validating design parameters and ensuring that the conveyor meets operational requirements with regard to strength, durability, and safety under various loading scenarios.

4.2.5.1 Static Structural Analysis for Cell to cell Conveyor.

The critical loading positions on the conveyor surface, depicted in the accompanying diagram, are strategically located at both the front and rear ends. These positions have been identified through rigorous force assessment procedures, where weights are systematically applied to ascertain the maximum load capacity before any perceptible deformation occurs. The criterion for deformation tolerance is set at a threshold of 0.0002 millimeters, beyond which structural integrity may be compromised. The red arrow in the diagram denotes the magnitude of the load application on the conveyor surface.

This analytical approach is indispensable for evaluating the structural robustness of the conveyor system and ensuring its operational reliability under diverse and fluctuating load conditions. By delineating permissible weight limits, this analysis safeguards against structural deformations that could potentially impair the conveyor's functionality and performance within defined operational parameters.

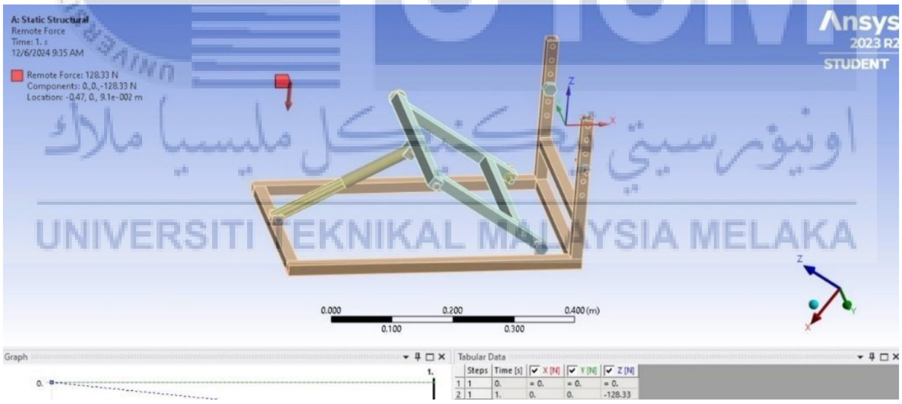


Figure 4.6: Remote force

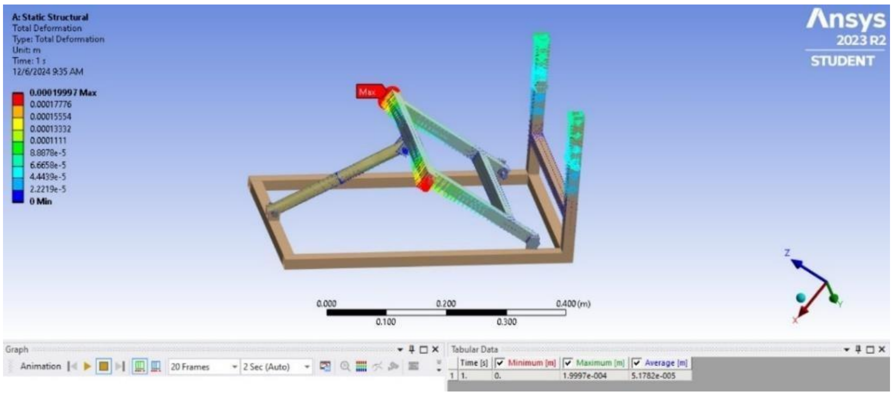


Figure 4.7: Maximum point

Table of Design Points

	A	B	C	D
1	Name	P1 - Remote Force Z Component	P2 - Total Deformation Maximum	P3 - Safety Factor Mi
2	Units	N	mm	
3	DP 0	-100	0.15582	6.01
4	DP 1 (Current)	-128.33	0.19997	4.6832
*				

Figure 4.8: Design point

The findings from this analysis indicate that the maximum load capacity for the conveyor system is 128.33 Newtons (N). Any load exceeding this threshold on the critical force surface results in deformation at its maximum point. This critical force surface represents the specific area where the conveyor is most susceptible to structural deformation under applied loads. The identified load capacity of 128.33 N serves as a crucial determinant in ensuring the conveyor's operational integrity and durability, highlighting the importance of adhering to specified load limits to prevent structural failure and maintain optimal performance.

4.3 Evaluate the Functionality and Usability of the Cell to Cell Conveyor Prototype

This study was rigorously assessed using a diverse strategy that included the involvement of four test subjects. A conveyor's usefulness and ability may be measured by its movement. The main components are the requisite speed and energy. The energy in question is electrical current. In this part, the experiments are designed to analyze the connection between speed, electric current, load, and angle. The speed test is performed using a tachometer, which measures the rotating speed of the conveyor roller. Following that, the electric current is tested using an Ammeter that is linked in parallel with the conveyor motor. Both of these tests are carried out by applying resistance, which is the difference between the angle and the load.

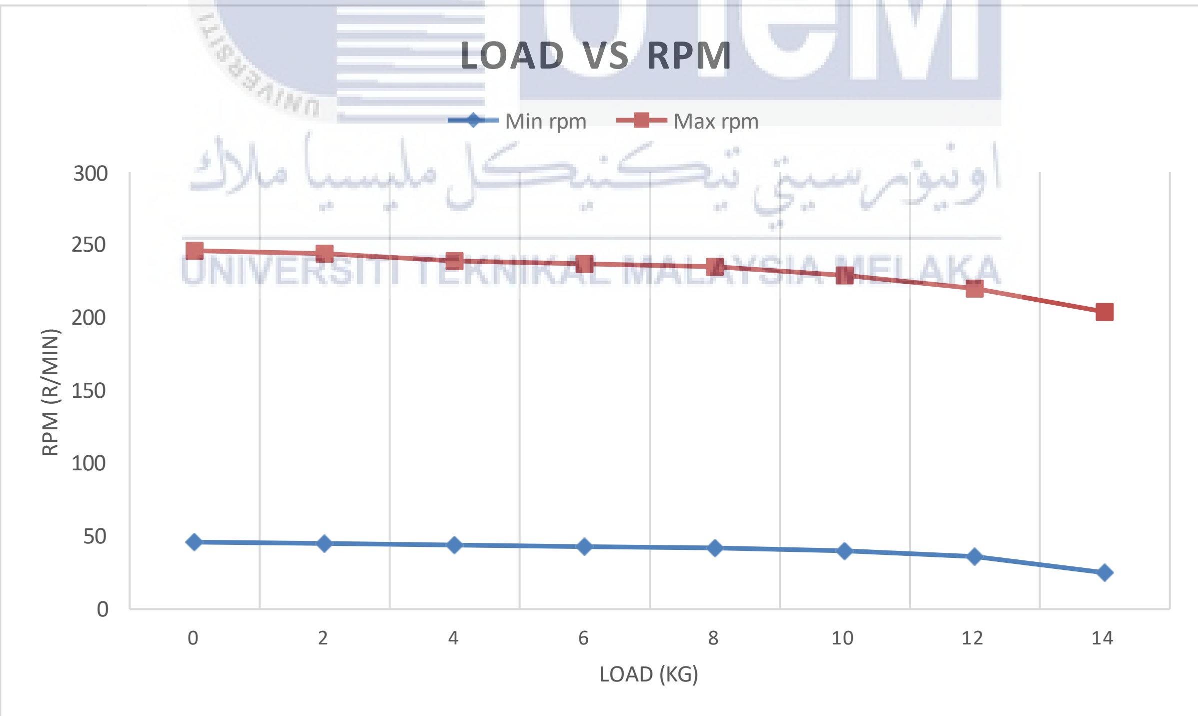
The experimental testing protocol includes segmentation into maximum and minimum operational speeds to comprehensively assess conveyor performance. This segmentation aims to provide a holistic overview based on varying conveyor capacities. Essential metrics such as electric current consumption are recorded at both maximum and minimum operational speeds. Initially, readings based on table below encompassing maximum and minimum speeds and corresponding electric current values are obtained to establish a baseline for further analysis.

Table 4.8: Rpm and current result

Revolution Per Minute (r/min)		Current (A)	
Maximum	246	Maximum	2.36
Minimum	46	Minimum	2.29

4.3.1 Results of Speed Test against load

In this section, the pre-adoption testing approach for the cell to cell conveyor is outlined. In the conducted speed tests, the conveyor operates under load conditions. The objective of these tests is to assess the operational capability of the conveyor system in fulfilling predefined task scenarios and performance criteria. Through analysis of load variations documented in Graph 4.1, this study aims to evaluate the potential impact of load changes on the conveyor's speed consumption. Specifically, it seeks to determine whether fluctuations in load can influence the operational parameters of the conveyor system.



Graph 4.1: Load vs rpm

Table 4.9: Result of load vs rpm

	0	2	4	6	8	10	12	14
Min rpm	46	45	44	43	42	40	36	25
Max rpm	246	244	239	237	235	229	220	204

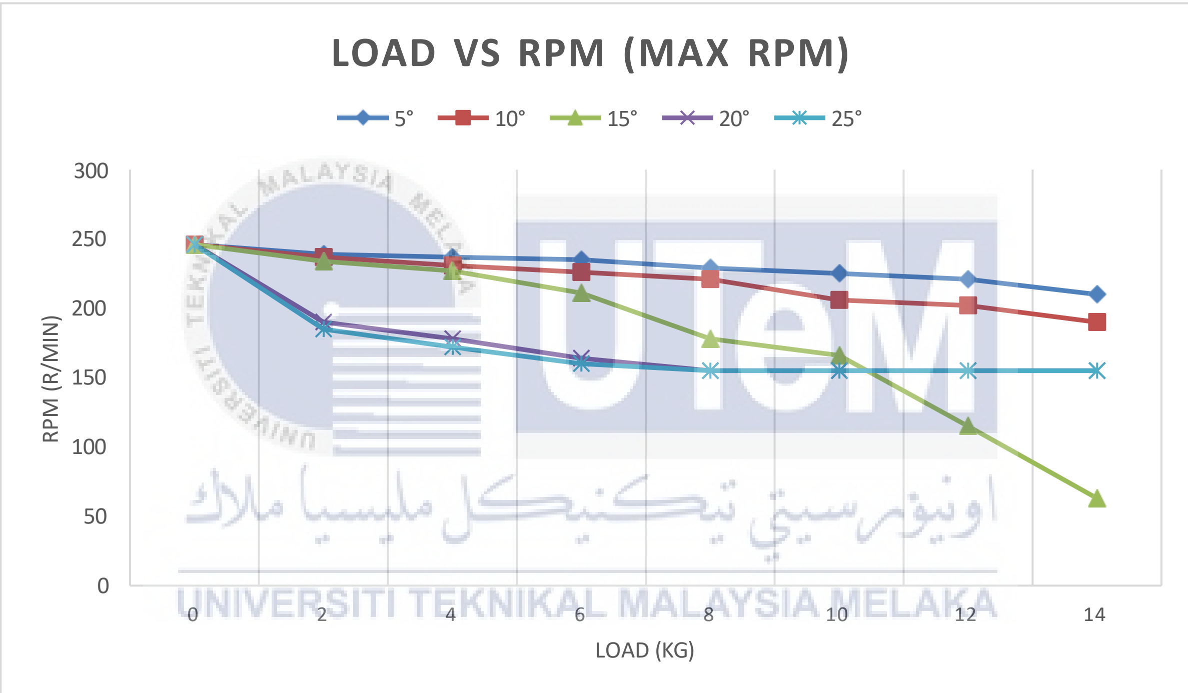
The analysis of the provided data indicates variations in speed of a system in response to changes in applied load, expressed in kilograms (kg). At maximum speed, the observed trend reveals a reduction in rotational speed from 246 rpm with no load (0 kg) to 204 rpm under a load of 14 kg, reflecting a total decrease of 42 rpm across this weight range. Notably, the most significant reduction of 16 rpm occurs specifically at the 14 kg weight. Smaller reductions in speed are observed at intermediate weights: at 2 kg, 6 kg, and 8 kg, each showing a decrease of 2 rpm, while the 4 kg weight exhibits a reduction of 5 rpm. The 10 kg weight demonstrates a decrease of 6 rpm, and the second largest reduction is noted at 12 kg with a speed decrease of 9 rpm.

Similarly, analysis of minimum speed readings indicates a consistent decline in rotational speed across varying weights. Starting from 46 rpm at no load, the speed decreases to 25 rpm at 14 kg, resulting in a total reduction of 21 rpm across this weight spectrum. The most substantial reduction occurs at 14 kg, where the speed drops by 11 rpm. Minor reductions of 1 rpm are observed at weights of 2 kg, 4 kg, 6 kg, and 8 kg, with the 10 kg weight showing a decrease of 2 rpm, and the 12 kg weight exhibiting a reduction of 4 rpm.

These findings suggest a systematic relationship between applied load and rotational speed, highlighting how increased weight leads to reduced rotational velocities both at maximum and minimum operational speeds. The variations observed underscore the influence of load on system performance, crucial for understanding and optimizing the operational parameters of such mechanical systems.

4.3.2 Results of Speed Test against load and angle

In the conducted speed test, the conveyor system operates under varying load and angle conditions. The primary objective of this investigation is to assess the operational efficacy of the dispatcher system in achieving predefined task scenarios and performance metrics. By analyzing the documented load and angle variations, specifically depicted in Graph 4.4 for maximum speed and Graph 4.5 for minimum speed, this study endeavors to evaluate the potential influence of these variations on conveyor speed utilization. The specific aim is to ascertain whether fluctuations in load and angle could impact the operational parameters of the conveyor system.



Graph 4.2: Load vs rpm (Max rpm)

Table 4.10: Result of load vs rpm (Max rpm)

	0	2	4	6	8	10	12	14
5°	246	239	237	235	229	225	221	210
10°	246	237	231	226	221	206	202	190
15°	246	234	227	211	178	166	115	63
20°	246	190	178	164	155	155	155	155
25°	246	185	172	160	155	155	155	155

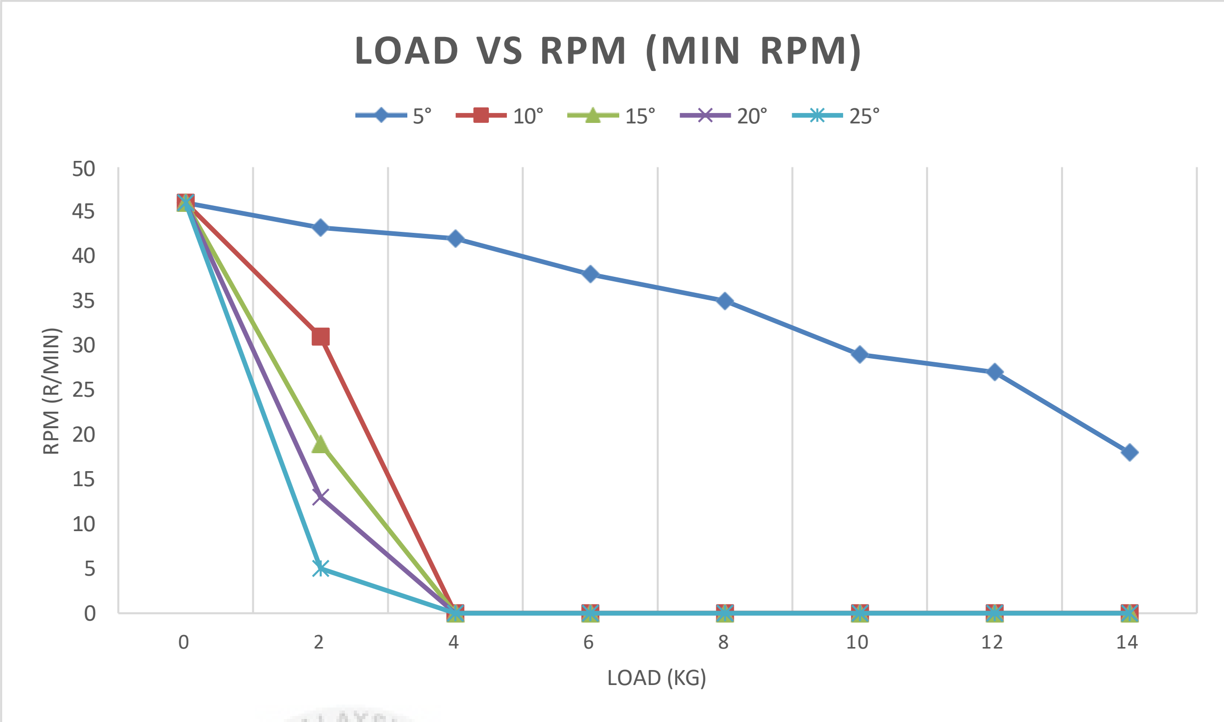
The graphical representation delineates the operational characteristics of a conveyor system at different incline angles (5°, 10°, 15°, 20°, and 25°) across varying load conditions. At a 5° incline, the graph illustrates a progressive decrease in rotational speed from 0 kg to 14 kg, resulting in an aggregate reduction of 36 rpm. Notably, the most significant decline of 11 rpm occurs precisely at the 14 kg load, with smaller reductions of 7 rpm at 2 kg, and 2 rpm each at 4 kg and 6 kg, followed by decreases of 6 rpm at 8 kg and 10 kg, and 4 rpm at 12 kg.

At a 10° incline, there is a consistent decrement in speed across the weight spectrum, totaling 56 rpm. The most substantial reduction is observed at 10 kg, amounting to a decrease of 15 rpm, followed by a reduction of 12 rpm at 14 kg. Minor reductions include 9 rpm at 2 kg, 6 rpm at 4 kg, and 5 rpm each at 6 kg, 8 kg, and 10 kg.

The 15° incline manifests distinct phases of speed reduction: a marginal decline from 0 kg to 6 kg, a moderate decrease from 6 kg to 8 kg, and a substantial drop from 12 kg to 14 kg. Specifically, reductions of 12 rpm, 7 rpm, and 16 rpm are observed at 0 kg, 2 kg, 4 kg, and 6 kg, respectively. A notable decrease of 33 rpm is noted at 8 kg, with subsequent reductions of 12 rpm at 10 kg, followed by the most significant drops of 51 rpm and 52 rpm at 12 kg and 14 kg, respectively.

Both the 20° and 25° inclines exhibit comparable patterns of speed reduction across various loads, with distinctions evident at 2 kg, 4 kg, and 6 kg weights. Notably, both inclines demonstrate the most pronounced reduction at 2 kg, with decreases of 56 rpm and 61 rpm, respectively. At 4 kg, angle 20° displays a decrease of 12 rpm, while angle 25° shows a slightly higher reduction of 13 rpm. Moving to 6 kg, angle 20° decreases by 14 rpm, whereas angle 25° decreases by 12 rpm. As the load increases to 8 kg, angle 20° exhibits a reduction of 9 rpm, whereas angle 25° decreases by 5 rpm. Notably, from 10 kg to 14 kg, both inclines maintain a consistent speed of 155 rpm, indicating a plateau in rotational speed within this weight range.

These findings underscore the intricate variations in speed reduction influenced by incline angle and applied load, crucial for comprehending the operational dynamics of conveyor systems across diverse operational scenarios.



Graph 4.3: Load vs rpm (Min rpm)

Table 4.11: Result of load vs rpm (Min rpm)

	0	2	4	6	8	10	12	14
5°	46	43.2	42	38	35	29	27	18
10°	46	31	0	0	0	0	0	0
15°	46	19	0	0	0	0	0	0
20°	46	13	0	0	0	0	0	0
25°	46	5	0	0	0	0	0	0

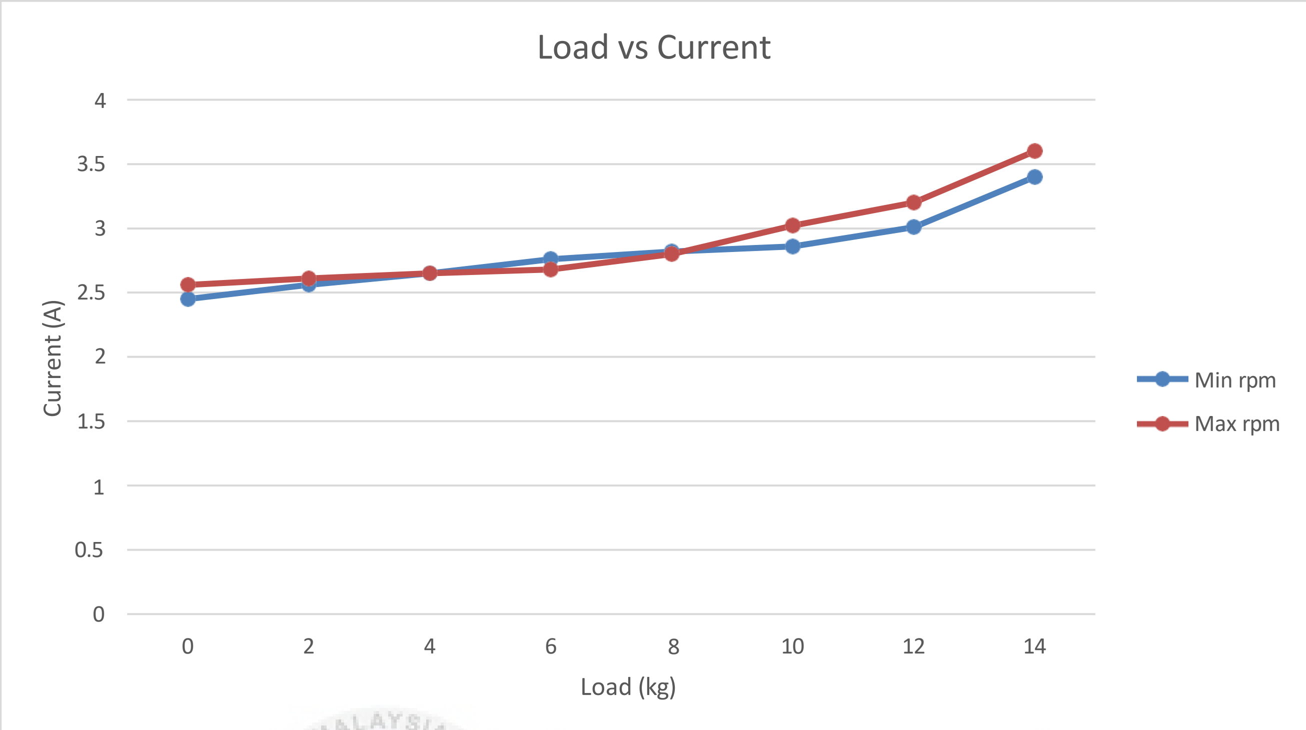
The presented graph delineates the minimum rotational speed (rpm) characteristics of a conveyor system across multiple incline angles (5°, 10°, 15°, 20°, and 25°) under varying loads. At a 5° incline, the graph depicts a consistent decrease in rpm from 0 kg to 14 kg, with the most notable reduction occurring at the maximum load of 14 kg, resulting in a decrease of 9 rpm. Conversely, the smallest reduction is observed at 4 kg, amounting to a decrease of 1 rpm. Intermediate reductions include 3 rpm at 2 kg, 4 rpm at 6 kg, 7 rpm at 8 kg, 6 rpm at 10 kg, and 8 rpm at 12 kg, representing the second-highest reduction in rpm across the range of tests.

In the cases of angles 10°, 15°, 20°, and 25°, a similar pattern of rpm decline is observed. Initially, there is a significant rpm reduction from 0 kg to 4 kg, followed by a consistent rpm value of 0 from 4 kg to 14 kg. The distinguishing factor among these angles lies in the specific rpm values. At 2 kg, angle 10° exhibits the most substantial rpm decrease of 31 rpm, followed by angle 15° with 19 rpm, angle 20° with 13 rpm, and angle 25° with 5 rpm. Notably, angle 15° shows the most pronounced reduction of 31 rpm at 4 kg weight, distinguishing it with the highest rpm decrease values among the incline angles.

Overall, the graph highlights the influence of incline angles on the minimum rpm performance of conveyor systems under varying load conditions. Higher inclines generally result in more significant reductions in rotational speed, indicative of increased gravitational resistance and load-induced friction experienced by the conveyor system. These findings provide valuable insights for optimizing conveyor system design and operational efficiency in industrial applications, where maintaining appropriate operational speeds under varying incline and load conditions is critical.

4.3.3 Results of Current Test against load

In this section, the pre-adoption testing approach for the cell to cell conveyor is outlined. In the conducted electric current tests, the conveyor operates under load conditions. The objective of these tests is to assess the operational capability of the conveyor system in fulfilling predefined task scenarios and performance criteria. Through analysis of load variations documented in Graph 4.3, this study aims to evaluate the potential impact of load changes on the conveyor's electric current consumption. Specifically, it seeks to determine whether fluctuations in load can influence the operational parameters of the conveyor system.



Graph 4.4: Load vs current

Table 4.12: Result of load vs current

	0	2	4	6	8	10	12	14
Min rpm	2.45	2.56	2.65	2.76	2.82	2.86	3.01	3.4
Max rpm	2.56	2.61	2.65	2.68	2.8	3.02	3.2	3.6

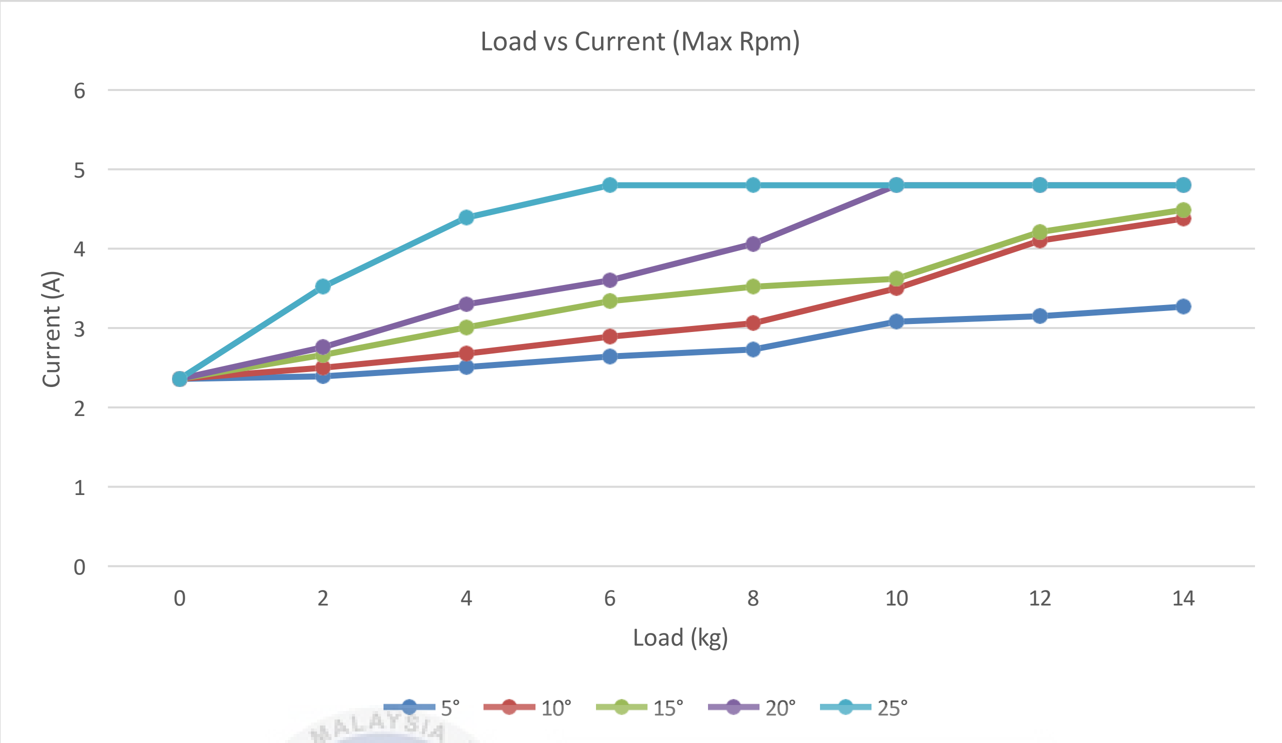
The provided graph depicts variations in electric current at maximum and minimum speeds across different weights (0 kg to 14 kg) applied to a test apparatus. At maximum speed, the electric current shows a consistent increase throughout the weight range, with an overall difference of 1.04 A from 0 kg to 14 kg. Notably, the most substantial increases occur at the higher weights of 8 kg to 14 kg. Specifically, at 14 kg, the electric current increases by 0.4 A, marking the highest increment observed, followed by a 0.22 A increase at 10 kg, 0.18 A at 12 kg, and 0.12 A at 8 kg. Conversely, marginal increases are noted at lower weights: 0.05 A at 2 kg, 0.04 A at 4 kg, and the smallest increase of 0.03 A at 6 kg.

Conversely, at minimum speed settings, the electric current also exhibits an upward trend across the weight spectrum from 0 kg to 14 kg, totaling a difference of 0.95 A. Notably, the increases are more pronounced towards the end of the test, particularly at 12 kg and 14 kg weights. The highest increase occurs at 14 kg, where the electric current rises by 3.9 A, followed by 0.15 A at 12 kg, and 0.04 A at 8 kg. Modest increases are observed at lighter loads: 0.11 A at 2 kg, 0.09 A at 4 kg, and 0.11 A at 6 kg.

These observations underscore the dependency of electric current on applied weight and operational speed settings, highlighting how variations in load affect electrical consumption in the tested apparatus. Such insights are pertinent for understanding and optimizing power consumption in mechanical systems under differing operational conditions.

4.3.4 Results of Current Test against load and angle

In the conducted speed test, the conveyor system operates under varying load and angle conditions. The primary objective of this investigation is to assess the operational efficacy of the dispatcher system in achieving predefined task scenarios and performance metrics. By analyzing the documented load and angle variations, specifically depicted in Graph 4.4 for maximum speed and Graph 4.5 for minimum speed, this study endeavors to evaluate the potential influence of these variations on conveyor current. The specific aim is to ascertain whether fluctuations in load and angle could impact the operational parameters of the conveyor system.



Graph 4.5: Load vs current (Max rpm)

Table 4.13: Result of load vs current (Max rpm)

	0	2	4	6	8	10	12	14
5°	2.36	2.39	2.51	2.64	2.73	3.08	3.15	3.27
10°	2.36	2.5	2.68	2.89	3.06	3.5	4.1	4.38
15°	2.36	2.66	3.01	3.34	3.52	3.62	4.21	4.49
20°	2.36	2.76	3.3	3.6	4.06	4.8	4.8	4.8
25°	2.36	3.52	4.39	4.8	4.8	4.8	4.8	4.8

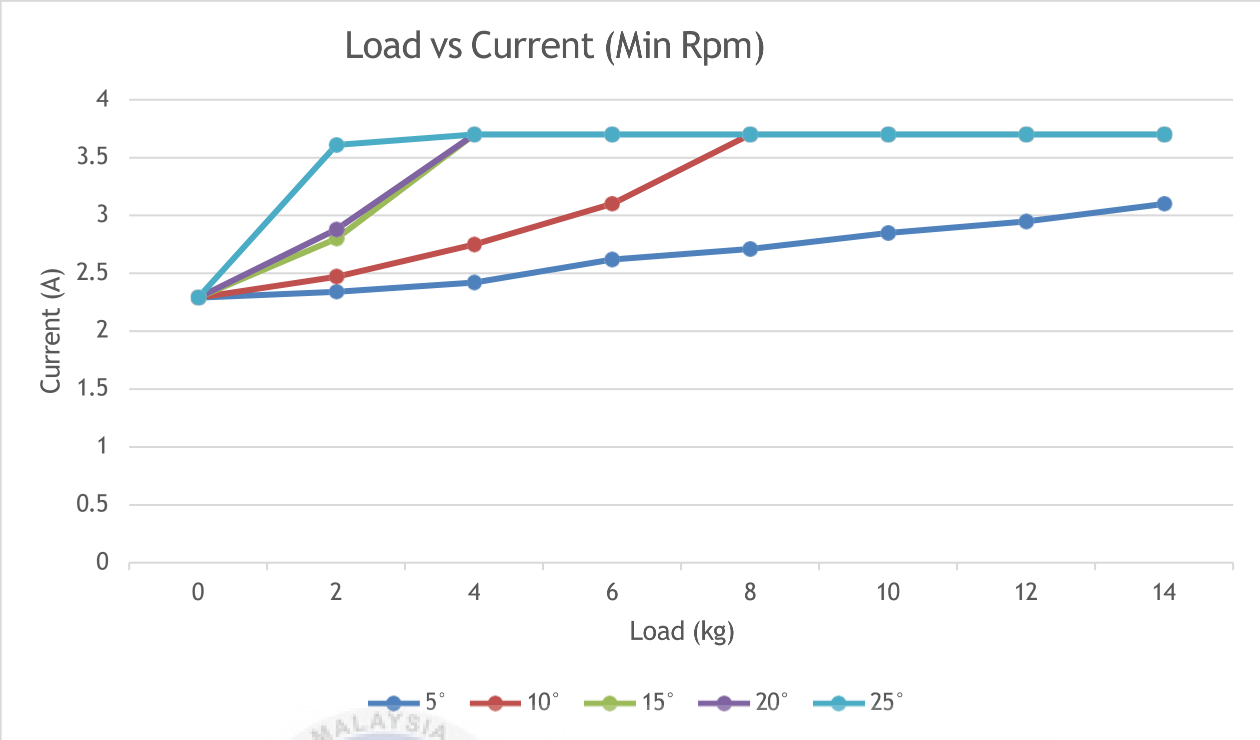
The provided graph illustrates the electric current variations across different incline angles (5°, 10°, 15°, 20°, and 25°) and varying loads (0 kg to 14 kg) in a test apparatus. At a 5° incline, the electric current demonstrates a consistent increase across the weight range, totaling 0.91 A from 0 kg to 14 kg. The most significant increment occurs at 10 kg, with a rise of 0.35 A. Minor increases are observed at other weights: 0.03 A at 2 kg, 0.12 A at 4 kg, 0.13 A at 6 kg, 0.09 A at 8 kg, 0.06 A at 12 kg, and 0.12 A at 14 kg, where 2 kg exhibits the least increase (0.03 A), and 6 kg registers the second highest (0.13 A).

At a 10° incline, notable increases in electric current are observed from 10 kg to 14 kg. The highest increment occurs at 12 kg (0.6 A), constituting 30% of the total increase from 0 kg to 14 kg (2.02 A). Additionally, increases include 0.17 A at 8 kg, 0.44 A at 10 kg, and 0.28 A at 14 kg. Moderate increases are noted from 2 kg to 8 kg: 0.14 A at 2 kg, 0.18 A at 4 kg, 0.21 A at 6 kg, and 0.17 A at 8 kg, with 6 kg showing the second highest increase.

At a 15° incline, the electric current exhibits a steady rise, with noticeable increments from 10 kg to 14 kg weights. Specifically, increments are 0.30 A at 2 kg, 0.35 A at 4 kg, 0.33 A at 6 kg, 0.18 A at 8 kg, and 0.1 A at 10 kg. The most significant increase is at 12 kg (0.59 A), covering 27.7% of the total increase from 2 kg to 14 kg (2.13 A), followed by 0.28 A at 14 kg, while the lowest increase is observed at 10 kg.

Angles 20° and 25° exhibit similar trends from 10 kg to 14 kg, with a notable distinction at 6 kg for angle 25°. At 20°, the electric current increases steadily up to 10 kg, peaking at 0.74 A at 10 kg and showing the smallest increase at 6 kg (0.3 A). Increment values are 0.4 A at 2 kg, 0.54 A at 4 kg, and 0.46 A at 8 kg. At 25°, the current rises from 0 kg to 6 kg, with the highest increase at 2 kg (1.16 A), followed by 0.87 A at 4 kg and 0.41 A at 6 kg, where the lowest increase is observed.

These observations underscore the significant influence of both incline angle and applied load on electric current consumption, providing valuable insights into the electrical characteristics of the tested apparatus under maximum speed conditions across diverse operational scenarios. Such insights are critical for optimizing power efficiency and understanding the electrical demands of mechanical systems operating under varying incline angles and load conditions in industrial settings.



Graph 4.6: Load vs current (Min rpm)

Table 4.14: Result of load vs current (Min rpm)

	0	2	4	6	8	10	12	14
5°	2.29	2.34	2.42	2.62	2.71	2.85	2.95	3.1
10°	2.29	2.47	2.75	3.1	3.7	3.7	3.7	3.7
15°	2.29	2.8	3.7	3.7	3.7	3.7	3.7	3.7
20°	2.29	2.88	3.7	3.7	3.7	3.7	3.7	3.7
25°	2.29	3.61	3.7	3.7	3.7	3.7	3.7	3.7

In the depicted graph, the electric current characteristics of a system inclined at angles 5°, 10°, 15°, 20°, and 25° are analyzed across varying weights from 0 kg to 14 kg. At 5° inclination, there is a consistent increase in electric current from 0 kg to 14 kg, totaling an increase of 0.81 A. Notable increments include 0.05 A at 2 kg, 0.08 A at 4 kg, 0.2 A at 6 kg, 0.09 A at 8 kg, 0.14 A at 10 kg, 0.1 A at 12 kg, and 0.15 A at 14 kg. The highest increase is observed at 6 kg (0.2 A), while the lowest is at 2 kg (0.05 A).

At 10° incline, the electric current increases steadily up to 8 kg, where it peaks at 0.6 A. From 8 kg to 14 kg, the current remains constant at 3.7 A, indicating saturation. Notable increases include 0.18 A at 2 kg, 0.28 A at 4 kg, 0.35 A at 6 kg, and 0.6 A at 8 kg. The highest increase occurs at 8 kg, and the smallest increase is at 2 kg.

Angle 15° shows a pattern akin to angle 20°, where the electric current increases consistently up to 4 kg, and then remains stable at 3.7 A from 4 kg to 14 kg. At 2 kg, the electric current is 2.8 A, with an increase of 0.59 A, whereas at angle 20°, it reaches 2.88 A with an increase of 0.67 A at 2 kg.

Angle 25° demonstrates an increase in electric current only up to 4 kg, reaching a peak increase of 1.32 A at 2 kg, followed by a minor increase of 0.09 A at 4 kg. Beyond 4 kg, the electric current remains constant at the highest level of 3.7 A.

These observations underscore the interdependency of electric current on both incline angle and applied load at minimum rotational speeds, elucidating the operational characteristics and limits of the system under diverse incline and load conditions in experimental settings. Such insights are crucial for comprehending the electrical demands and optimizing the performance of mechanical systems across varying operational scenarios in industrial applications.

4.4 Discussion

In the realm of mechanical systems, the study of load versus rotational speed (rpm) and load versus electric current offers profound insights into system behavior across varying operational parameters, particularly at maximum and minimum rpm settings.

The relationship between load and rotational speed at maximum rpm elucidates how increasing loads impact the system's ability to maintain desired operational speeds. As load intensifies, mechanical resistance and frictional forces escalate, resulting in a discernible reduction in rotational speed (Yu et al., 2018). This trend is pivotal for understanding operational limitations and optimizing system performance under high-speed conditions. Conversely, at minimum rpm settings, where precision and controlled movements are critical, heavier loads may impose higher torque demands, affecting the achievable minimum operational speed.

Relationship expression of relational speed and load.

$$T = 9550\frac{p}{n}$$

Where p is power of electromotor,kW, n is the rotational speed of electromotor,r/min.

The worktable's output torque is:

$$T_1 = \eta T$$

In the context of mechanical systems, η total represents the overall efficiency, encompassing factors such as coupling efficiency, gear transmission efficiency, bearing efficiency, and assembly efficiency. The relationship between rotational speed and load can be inferred based on the equilibrium condition where the output torque of the worktable equals the torque required for shearing.

In practical terms, this relationship describes how the rotational speed of a system varies as the load changes. When the torque applied to the worktable reaches the torque needed for shearing, it signifies a balance point where the system's rotational speed stabilizes or varies in a predictable manner based on the load imposed.

This principle is fundamental in mechanical engineering applications, guiding the design and operation of systems where torque, rotational speed, and efficiency are critical parameters influencing performance and functionality. Understanding and analyzing this relationship aids in optimizing system design, predicting operational characteristics, and ensuring efficient performance under varying conditions of load and speed.

$$\omega = \frac{\eta T}{z \mu r^2 \left(\dfrac{A_s}{h_0 \sqrt[3]{\dfrac{w_0}{w_0 + w}}} + \dfrac{A_r}{t} \right)}$$

The correlation between load and electric current consumption provides crucial insights into the electrical demands of mechanical systems under varying loads. At maximum rpm, the graph depicting load versus current illustrates an increase in electrical consumption as load rises. This rise is attributed to the heightened mechanical resistance necessitating greater electrical power input to maintain operational speed and overcome resistive forces (Lyon et al., 2019.). Conversely, at minimum rpm settings, the load versus current relationship highlights baseline electrical requirements necessary for sustaining lower operational speeds across different load conditions, underscoring the system's electrical demands even at reduced speeds.

In the realm of electric motors, the relationship between power, voltage, current, speed, and torque is dynamic and interdependent, influencing the motor's performance characteristics. The power input into a motor is calculated by multiplying the voltage across its terminals by the current flowing through them (P = V * I). Conversely, the output power of the motor is determined by the product of its speed and torque.

The power output of a motor varies along with its speed and torque. At zero torque or zero speed, the power output is zero. As torque and speed increase from these baseline points, the power output rises, reaches a peak, and subsequently diminishes. This characteristic curve reflects the motor's ability to convert electrical energy into mechanical power under different operational conditions.

In practical terms, for a DC motor, speed is directly proportional to the applied voltage, while torque correlates with the current drawn by the motor. Increasing the load and requiring higher torque necessitates a corresponding increase in current drawn by the motor. Adjusting the motor's speed involves varying the applied voltage higher voltage for increased speed and lower voltage for reduced speed.

Integrating analyses of load versus rpm and load versus current provides a holistic understanding of system performance across its operational spectrum. Comparative examination of maximum and minimum rpm scenarios alongside their respective current profiles facilitates comprehensive insights into system efficiency, energy consumption patterns, and operational thresholds under diverse load conditions. This integrated approach informs strategic decision-making in system design, maintenance planning, and operational optimization to enhance overall performance, mitigate energy consumption, and ensure reliability in industrial applications.

In summary, the academic discussion on load versus rpm and load versus current dynamics underscores their critical role in engineering efficient mechanical systems. These analyses contribute fundamentally to optimizing performance, enhancing energy efficiency, and ensuring operational reliability across varied operational demands in industrial settings.

4.4.1 Comparison

The comparison between cell-to-cell conveyor systems and plate conveyors provides insight into their respective efficiency performances in various transport applications. In the specific case of transporting juice in glass bottles, the plate conveyor system was evaluated under different tilt angles: 0°, 3°, and 6°. This evaluation included parameters such as inverter frequency, conveyor belt linear speed, conveyor belt drive motor rotation speed, loading time, general transportation time, and distance between loads.

The experimental results indicated that as the tilt angle of the transport module increased, the efficiency of the plate conveyor system decreased. This decrease was most pronounced at a tilt angle of 6°. The transition from 3° to 6° tilt angles exhibited a particularly notable reduction in conveyor efficiency, warranting further investigation within this range (Caban et al., 2019).

In academic terms, these findings suggest that tilt angle significantly influences the operational efficiency of plate conveyors for transporting fragile cargo like glass bottles filled with juice. The observed decrease in efficiency at higher tilt angles underscores the importance of optimizing conveyor configurations to minimize potential inefficiencies and operational disruptions.

This comparative analysis reveals a parallel trend between the operational efficiency of the plate conveyor and the cell-to-cell conveyor, emphasizing the impact of tilt angle variation on their performance. A notable distinction lies in the response of rotational speed (rpm) reduction across these conveyor types. For instance, findings from the cell-to-cell conveyor experiment indicated a minimal rpm decrease from 221 rpm to 220 rpm (a decrease of 0.45%) within a tilt angle range of 0° to 5°. In contrast, the plate conveyor demonstrated no significant rpm reduction under similar conditions.

These results underscore the nuanced differences in conveyor design and their respective responses to tilt angle adjustments. Such distinctions are critical in evaluating and optimizing conveyor systems for efficient and reliable operation, particularly in industrial contexts where precise control over operational parameters is essential for maintaining throughput and minimizing potential disruptions in transport processes. Further research may explore these differences in greater detail to inform the development of tailored strategies for enhancing conveyor performance based on specific operational requirements and environmental conditions.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

This chapter offers an exhaustive synthesis of the research findings, aligning them with the predetermined objectives. Furthermore, it furnishes recommendations and suggestions to augment future research endeavors. This chapter will encapsulate an overview of the achievements in the development of the prototype for the passive exoskeleton. Subsequently, it will be succeeded by a conclusive assessment of the efficacy of the design.

5.1 Design Requirements for Developing Cell to cell Conveyor System Prototype

This study has identified user needs and design requirements for a cell to cell conveyor designed to assist improve the performance of carrying goods in the industry. These requirements were gathered through multiple study endeavors involving 10 existing market conveyors. Employing methodologies, including a collect information from market conveyor, performing benchmarking, and the construction of a House of Quality, the study determined and established design specifications for the development of the cell to cell conveyor. The study findings emphasize design requirements, including integrating features such as a medium-sized design and stable, integration with the user, facilitates angular movement and minimizes space consumption. Consequently, the incorporation of these specifications into the design and manufacturing processes ensures that the developed cell to cell conveyor system fulfills specific needs, addressing the first objective of the study.

5.2 Develop a Functional Prototype of ell to cell Conveyor System Prototype

This study addresses the operational challenges encountered by users of belt conveyors, particularly focusing on issues related to belt deviation that disrupt the goods delivery process. The development process of the cell-to-cell conveyor system involves several stages including concept design, concept screening, concept scoring, engineering drawings, and fabrication. Among the concepts evaluated, Concept D emerged as the optimal design with a score of 4.46 during the concept scoring phase. This design integrates a combination of roller and belt conveyors, tailored to enhance the efficiency of goods transportation. The conveyor system is capable of operating across incline angles ranging from 0 to 25 degrees, facilitating the movement of goods to elevated positions while maintaining stability and moderate dimensions.

Key features of Concept D include rollers integrated into the conveyor surface to mitigate the risk of goods becoming stuck and minimize friction. Finite Element Analysis (FEA), specifically static structural analysis, was employed to assess the load-bearing capacity of the prototype. The analysis revealed a maximum load capacity of 128.33 Newtons, indicating the conveyor's capability to support the applied load effectively without structural deformation.

The primary objective of developing the functional prototype of the cell-to-cell conveyor system was successfully achieved, aiming to enhance goods handling performance in industrial applications.

5.3 Evaluate the Functionality and Usability of the Cell to cell Conveyor System Prototype

This study provides a systematic evaluation of the functionality and usability of a developed cell-to-cell conveyor prototype, focusing on various operational parameters such as speed, electrical current, applied weights ranging from 2kg to 14kg, and incline angles from 5° to 25°. The investigation involved testing with six different scenarios to assess the conveyor's performance under different conditions.

The findings indicate that the designed cell-to-cell conveyor prototype meets operational requirements and demonstrates robust performance during testing. Specifically, at maximum operational speed settings, the conveyor successfully handles a maximum load of 14kg and operates efficiently at incline angles up to 25°, with the highest recorded electrical current consumption reaching 4.8A. Statistical analysis of the maximum load capacity, which was determined to be 128.33 N, confirms the conveyor's capability to exceed specified load limits effectively.

However, under minimal speed conditions, the conveyor's capacity is limited, supporting a maximum weight of only 4kg and functioning effectively up to an incline angle of 10°. This contrast underscores the operational dependency of the conveyor system on speed settings and load conditions.

In summary, the study highlights the efficacy and potential advantages of the cell-to-cell conveyor in managing heavy loads ranging from 2kg to 14kg across incline angles from 5° to 25°, demonstrating its suitability for industrial applications requiring efficient goods handling under varied operational settings.

5.4 Recommendation for Future Study

Based on the findings from the current study on the developed cell-to-cell conveyor system for goods delivery, several recommendations for future research emerge. Firstly, expanding the participant pool beyond the initial six subjects used in the current study would enhance the generalizability of findings and provide a more robust understanding of the conveyor system's performance across diverse user populations. Secondly, there is a need to investigate and implement advanced materials tailored for conveyor systems. Research should focus on materials with enhanced durability, reduced coefficient of friction, and superior wear resistance to extend conveyor lifespan and minimize maintenance requirements. Additionally, future studies should explore the integration of automation technologies, such as robotic arms and automated sorting systems, with conveyors to optimize material handling processes, increase productivity, and reduce labor costs associated with goods delivery operations. Furthermore, the development of smart dispatcher systems equipped with sensors and IoT capabilities is recommended to monitor real-time performance and implement predictive maintenance algorithms to optimize operational efficiency and minimize downtime. Lastly, conducting a comprehensive life cycle assessment (LCA) would evaluate the environmental impact of the linear conveyor system, including factors like energy consumption, carbon footprint, material utilization, and end-of-life disposal considerations. These recommendations collectively aim to advance the functionality, efficiency, and sustainability of cell-to-cell conveyor systems, ensuring their applicability and optimizing user acceptance in practical goods delivery scenarios.

5.5 Complexity

The study grapples with a nuanced array of complexities. Firstly, involves integrating various components such as rollers, belts, sensors, bearing, elektrik jack, shaft and control systems. Each component must be meticulously selected and integrated to ensure smooth operation and reliability under varying loads and environmental conditions. Moreover, the conveyor's mechanical design requires expertise in structural analysis, material science, and mechanical engineering principles. Factors such as load-bearing capacity, friction management, and durability must be carefully considered to prevent failures and optimize performance. The study encounters difficulty in achieving optimal performance involves conducting feasibility studies, simulations, and testing prototypes to validate design assumptions and operational parameters. This iterative process ensures that the conveyor system meets operational requirements and delivers expected performance metrics.. Furthermore, the investigation acknowledges inherent complexities stemming from variables such as addressing sustainability concerns involves selecting eco-friendly materials, optimizing energy efficiency, and minimizing environmental footprint throughout the lifecycle of the conveyor system. This requires adherence to regulatory standards and conducting life cycle assessments (LCA) to evaluate environmental impacts.

5.6 Sustainable Design and Development

The design and development of the cell-to-cell conveyor prototype for facilitating goods movement underscores a commitment to environmental stewardship through strategic material selection. Utilization of materials like aluminum plates and mild steel aligns with sustainability principles due to their recyclability and potential for reducing environmental impact. Incorporation of polymer and responsibly sourced nylon enhances durability and flexibility, further emphasizing lifecycle assessment and eco-friendly sourcing practices. This approach ensures the internal sustainability of the prototype design, promoting environmentally inclusive technological innovation for industrial applications in goods delivery.

Moreover, integrating cell-to-cell conveyor prototypes supports Sustainable Development Goal 11 (SDG 11) as depicted in Figure 5.1, which aims to foster inclusive, safe, resilient, and sustainable cities and human settlements. These conveyors enhance logistics and transportation systems by optimizing goods delivery efficiency, thereby reducing congestion and emissions within urban environments. The adoption of sustainable conveyor designs, incorporating advanced materials and energy-efficient technologies, contributes to resource efficiency by lowering energy consumption and minimizing the environmental footprint associated with logistics operations. Additionally, the modular and scalable nature of these systems supports resilient infrastructure, capable of adapting to the evolving needs of rapidly growing urban areas, including the efficient distribution of goods.

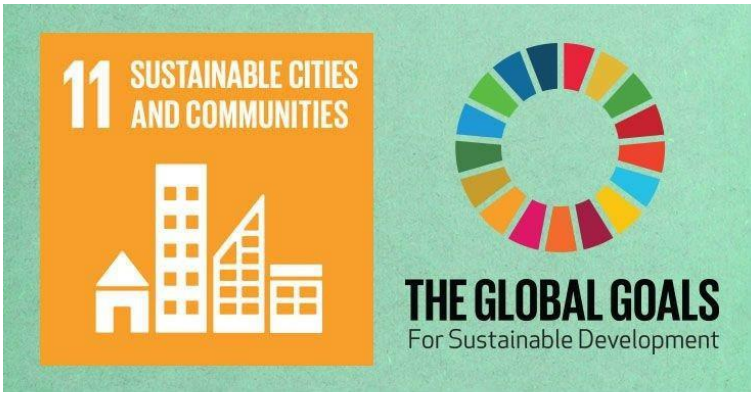


Figure 5.1: Sustainable development goal 11

5.7 Lifelong Learning (LLL) and Basic Entrepreneurship

Lifelong Learning (LLL) is integral to cultivating fundamental entrepreneurship within the realm of developing and implementing cell-to-cell conveyor systems. These systems, designed to optimize logistics and goods movement, necessitate a continuous learning approach to effectively adapt to technological advancements and market requirements. Basic entrepreneurship in this context encompasses acquiring and applying comprehensive knowledge and practical skills related to the design, operation, maintenance, and managerial aspects of conveyor systems.

LLL empowers entrepreneurs and stakeholders involved in cell-to-cell conveyor systems to stay abreast of evolving industry trends, regulatory frameworks, and emerging technologies. This ongoing learning process enables individuals to innovate, enhance system efficiency, and tackle challenges such as sustainability and operational optimization. For example, staying informed about advancements in materials science enables entrepreneurs to select environmentally sustainable and cost-effective materials for constructing conveyors, aligning with contemporary environmental standards.

Moreover, basic entrepreneurship in cell-to-cell conveyor systems entails developing proficiency in business management to navigate market dynamics, forge strategic partnerships, and identify growth opportunities. This includes comprehending customer needs, conducting market analysis, and formulating business strategies that capitalize on the capabilities of conveyor technology. LLL supports entrepreneurs in refining these entrepreneurial competencies, fostering a culture of innovation and adaptability crucial for sustaining and expanding ventures within the competitive logistics and industrial automation sectors.

In essence, LLL enhances basic entrepreneurship in cell-to-cell conveyor systems by equipping individuals with the knowledge, skills, and entrepreneurial mindset needed to drive technological innovation, operational efficiency, and sustainable business practices in logistics and goods transportation.

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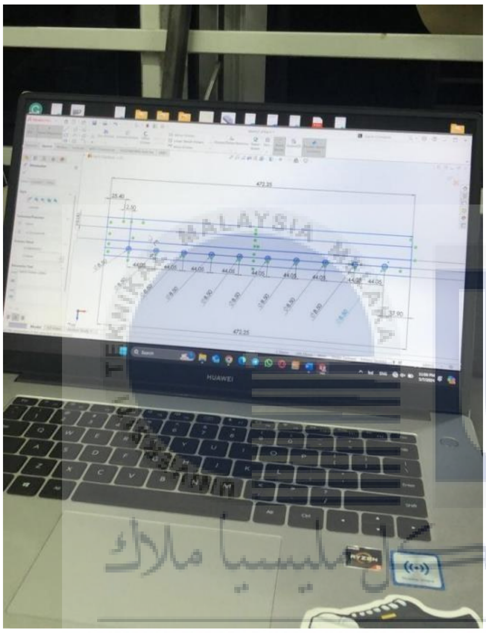
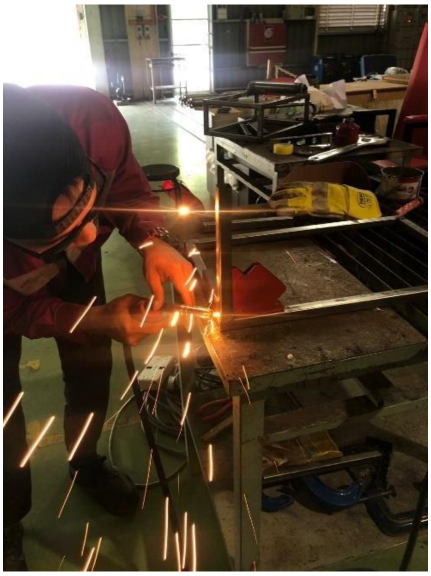
APPENDIXS

Appendix A: Fabrication of Prototype

Design, Cutting, Drilling



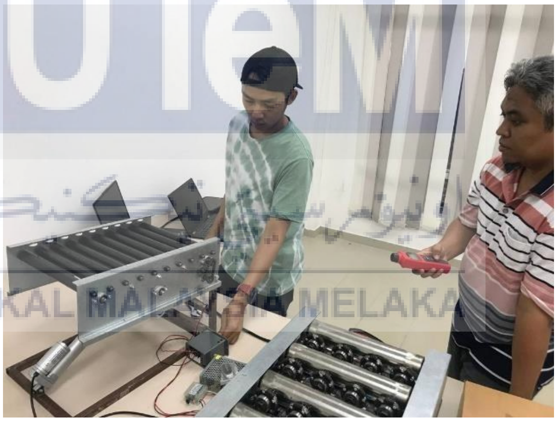
Welding, Laser Cut, Bending



Final Prototype

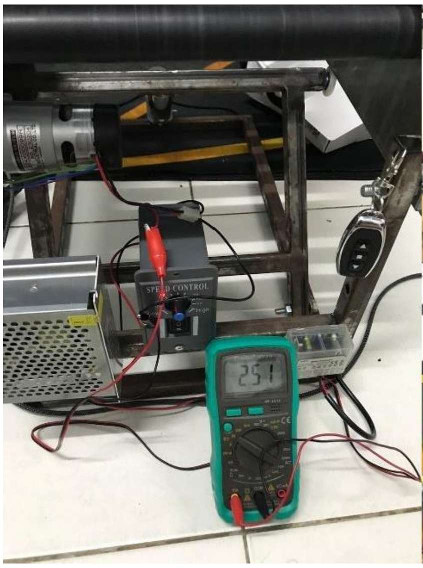
Appendix B: Functionality Test

Speed Test



Load Test

Current Test

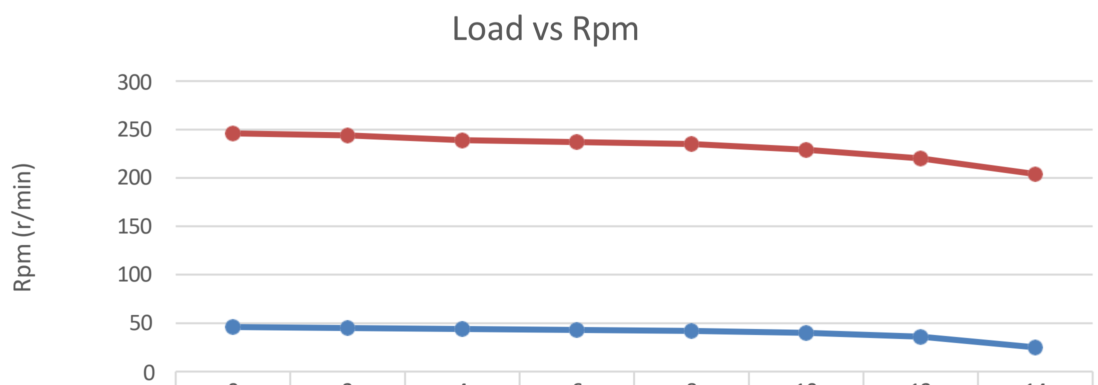


Range of motion testing

25 degree

0 degree

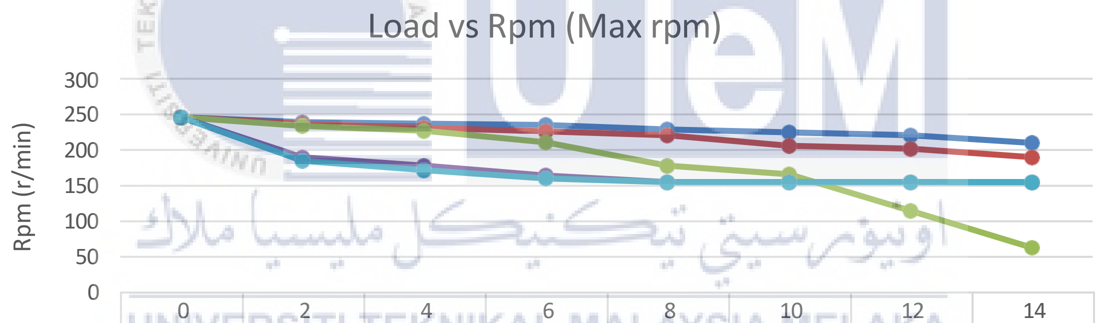
Appendix C: Results of Functionality Test



Load (kg)	0	2	4	6	8	10	12	14
Min rpm	46	45	44	43	42	40	36	25
Max rpm	246	244	239	237	235	229	220	204
Column1								

Load (kg)

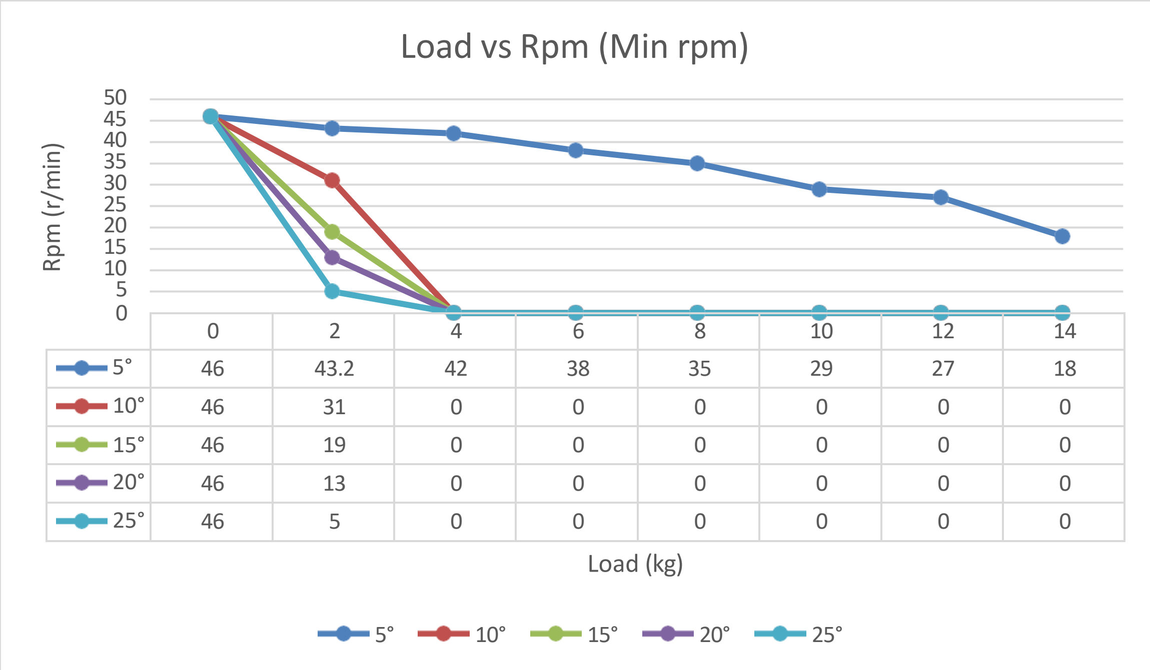
Min rpm Max rpm



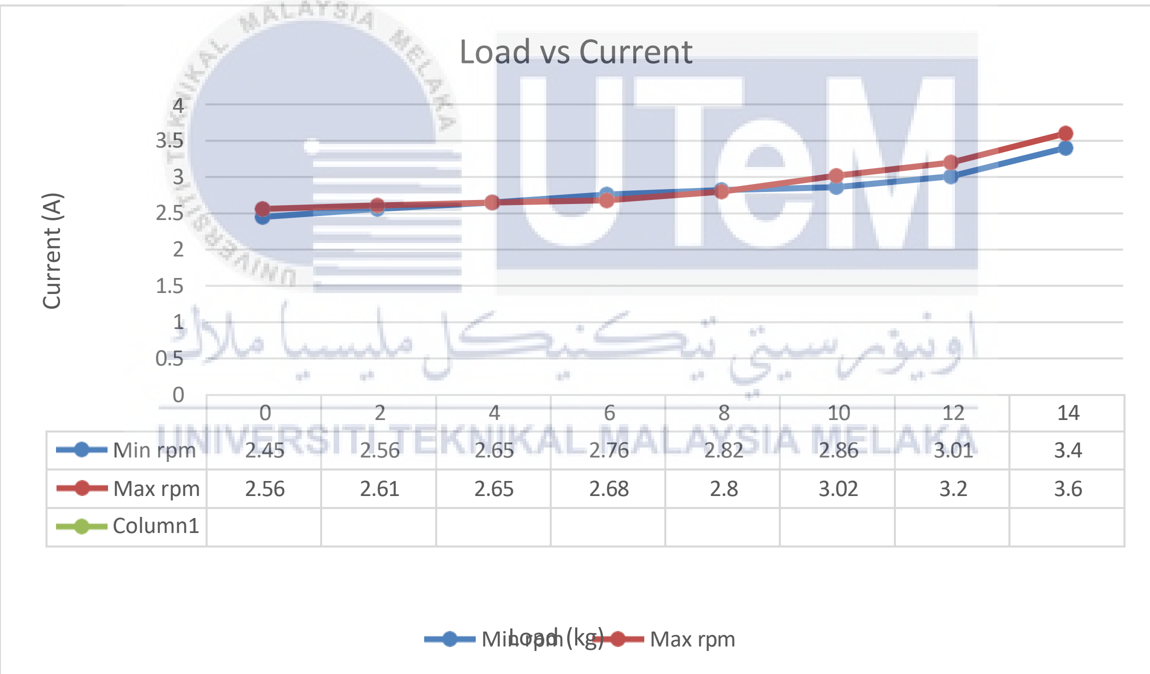
Load (kg)	0	2	4	6	8	10	12	14
5°	246	239	237	235	229	225	221	210
10°	246	237	231	226	221	206	202	190
15°	246	234	227	211	178	166	115	63
20°	246	190	178	164	155	155	155	155
25°	246	185	172	160	155	155	155	155

Load (kg)

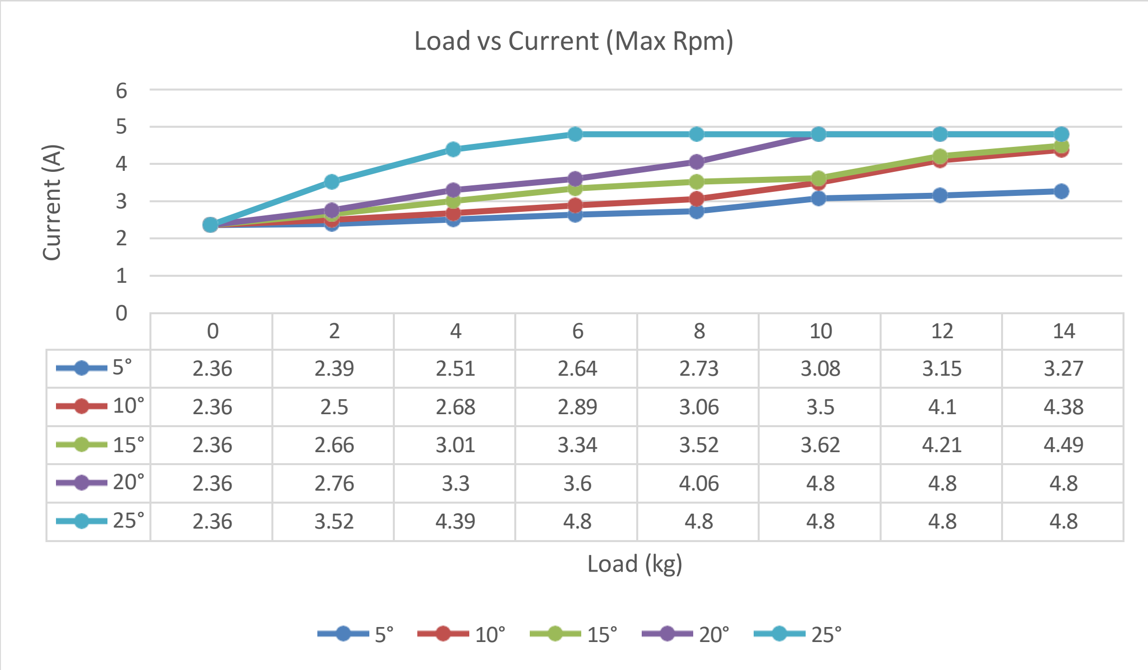
5° 10° 15° 20° 25°



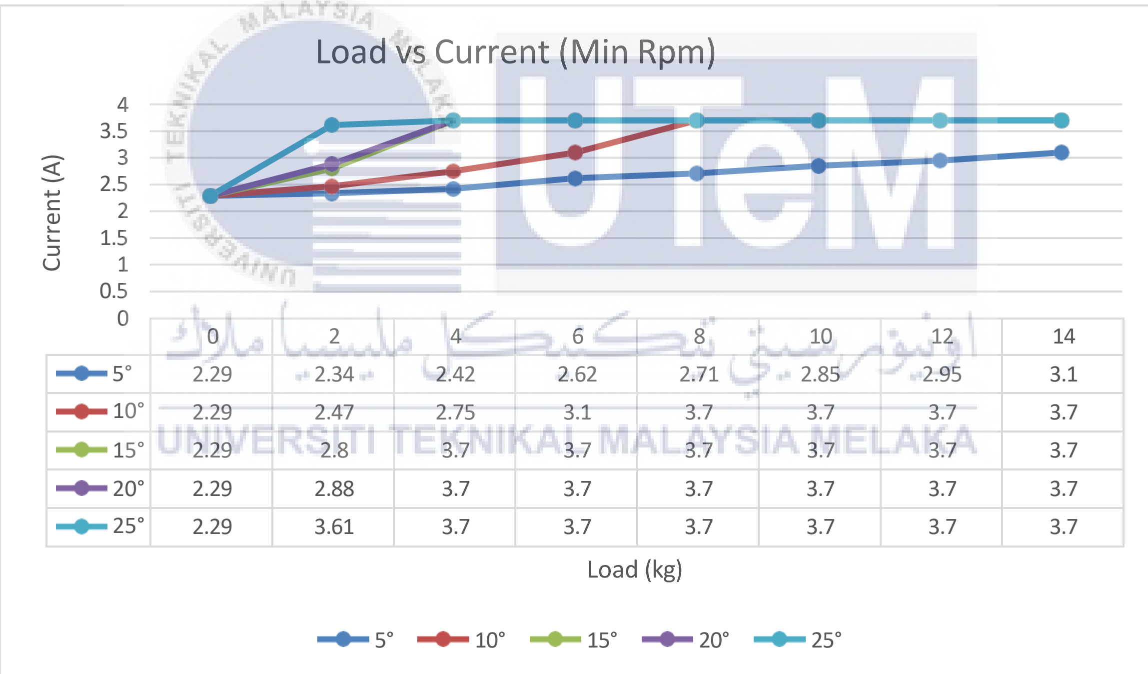
	0	2	4	6	8	10	12	14
5°	46	43.2	42	38	35	29	27	18
10°	46	31	0	0	0	0	0	0
15°	46	19	0	0	0	0	0	0
20°	46	13	0	0	0	0	0	0
25°	46	5	0	0	0	0	0	0



	0	2	4	6	8	10	12	14
Min rpm	2.45	2.56	2.65	2.76	2.82	2.86	3.01	3.4
Max rpm	2.56	2.61	2.65	2.68	2.8	3.02	3.2	3.6
Column1								



	0	2	4	6	8	10	12	14
5°	2.36	2.39	2.51	2.64	2.73	3.08	3.15	3.27
10°	2.36	2.5	2.68	2.89	3.06	3.5	4.1	4.38
15°	2.36	2.66	3.01	3.34	3.52	3.62	4.21	4.49
20°	2.36	2.76	3.3	3.6	4.06	4.8	4.8	4.8
25°	2.36	3.52	4.39	4.8	4.8	4.8	4.8	4.8



	0	2	4	6	8	10	12	14
5°	2.29	2.34	2.42	2.62	2.71	2.85	2.95	3.1
10°	2.29	2.47	2.75	3.1	3.7	3.7	3.7	3.7
15°	2.29	2.8	3.7	3.7	3.7	3.7	3.7	3.7
20°	2.29	2.88	3.7	3.7	3.7	3.7	3.7	3.7
25°	2.29	3.61	3.7	3.7	3.7	3.7	3.7	3.7