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Design and Fabrication of Feeder for Cardboard Folding Machine with Modular Approach

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Abstrak

Semakin berkembangnya industri seiring dengan banyaknya permintaan pasar membuat aspek efisien terhadap waktu dan tenaga perlu dikembangkan. Saat ini masih banyak industri pengemasan yang melakukan proses pengemasannya secara manual dan akan menjadi masalah ketika mendapatkan pesanan banyak dengan waktu yang singkat. Oleh karena itu, Penelitian ini bertujuan untuk merancang bangun *feeder* yang akan dirangkaikan pada *cardboard folding machine* sehingga dapat mengeluarkan lembaran kardus secara semi otomatis dan dapat mencegah lipatan kardus yang telah terlipat untuk membuka kembali, keduanya dapat mengurangi campur tangan operator. Terdapat pengujian performa dengan membandingkan hasil rancangan sebelum dan sesudah pengembangan untuk menemukan nilai produksi terbaik dalam variasi waktu dan kecepatan tertentu. Konsep pendekatan secara modular dipakai pada desain dan fabrikasi *feeder* ini sesuai dengan daftar kebutuhan pengguna yang membutuhkan alat yang dapat mengurangi campur tangan operator dan mudah diinstalasi. Hasil perbandingan performa *cardboard folding machine* mengalami peningkatan produksi pada variasi waktu dan kecepatan yang telah ditentukan karena pada proses *input* lembaran kardus, operator hanya akan menumpuk lembaran kardus yang selanjutnya dikendalikan melalui *feeder* gesek. Hasil *output* juga menunjukkan bahwa kardus yang telah terlipat tidak terbuka kembali akibat adanya roda penekan yang menekan. Konsep modular dinilai cocok pada pengembangan alat ini karena didukung oleh kesamaan seperti dimensi ukuran kardus (10x10x10 cm), jenis material konstruksi besi *hollow* galvanis (50x50mm), proses sambungan antar modul yang menggunakan mur baut, dan kesamaan ukuran dengan desain modul *cardboard folding machine* yang telah difabrikasi. Hal ini menjadikan penggunaan konsep modular dapat mempermudah proses instalasi dan mengurangi campur tangan operator dengan peningkatan hasil produksi.

Keywords:
design;
feeder;
modular;
cardboard folding machine;
fabrication;

Abstract

As industries evolve and market demands increase, there is a growing need to enhance efficiency in terms of time and energy. Many packaging industries still perform their processes manually, which becomes problematic when dealing with large orders and tight deadlines. Therefore, this research aims to design and develop input and output feeders to be integrated into a cardboard folding machine, allowing semi-automatic operation and preventing folded cardboard from unfolding, thereby reducing operator intervention. Performance testing compares the design results before and after development to find the best production value for time and speed variations. Modular approach is applied to the design and fabrication of the feeders based on user input, which requires a system that reduces operator intervention and is easy to install. Cardboard folding machine's performance comparison shows improved production across all time and speed variations. During the cardboard feeding process, the operator only needs to stack cardboard sheets, which automatically enters through the friction feeder. The output results also indicate the folded cardboard remains closed due to the pressure wheel mechanism maintaining the fold. The modular concept is deemed suitable development due to the uniform cardboard dimensions (10x10x10 cm), construction material (galvanized hollow iron, 50x50 mm), and the connection between modules with bolts. This modular approach simplifies installation and reduces operator intervention while improving production output.

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1. Introduction

The advancement of industries and the increasing market demand due to the growing number of consumers have led many industries to prioritize efficiency and effectiveness in each production unit to improve production outcomes and place customer satisfaction as their primary goal [1].

An industry has many units in each of its processes, one of which is the packaging unit. In this unit, there is a process that involves plain square cardboard sheets that will be glued to form a stack of cardboard sheets ready to be formed, packaged, and distributed [2]. If all these processes are done manually using human labor, it becomes a problem when faced with a large order, as the production speed does not meet the order target and the workers become exhausted [3]. Therefore, a machine is needed to help increase production output [4] to be more efficient [5], effective, and easy to operate [6].

One system that meets these criteria is a box folding machine system [7]. The development of this system has been previously done by Mechanical Engineering students at UPN Veteran Jakarta and the machine is called a cardboard folding machine. However, the cardboard folding machine created previously still has shortcomings, such as manually inputting the cardboard sheets with hands, requiring an operator to feed the sheets one by one onto the folding conveyor. Furthermore, in the output section, there is no mechanism to ensure the cardboard, which has been glued and formed into folds, does not revert to its original shape.

Considering the shortcomings of the cardboard folding machine, a feeder input mechanism is needed to work on separating cardboard sheets one by one onto the folding conveyor system and there should be an output feeder mechanism expected to stack the cardboard so it can be packaged by operators with dimensions matching the conveyor module that has been created.

The selection of modular concept is supported by the dimensional compatibility between the input feeder and the output feeder with the folding conveyor. Dimensional similarity is not only present in the size of the cardboard used but also in the similarity of the construction frame, which uses galvanized hollow steel with a size of 50x50 mm and the machine design size refers to the modules that have been created. The assembly process between modules does not require welding, so the disassembly and assembly process only uses nuts and bolts. Therefore, the use of modular concept not only facilitates the integration between the input feeder, folding conveyor, and output feeder but also simplifies the installation process of these three modules and making it easier to customize according to needs [8].

There are several previous studies with similar titles or concepts. The information gathered is used as a guide in the development of the input and output feeders for the cardboard folding machine. In the research conducted by Thivanka Kasun Gunawardena [9], the friction feeder mechanism was chosen because this system is suitable for the researcher’s test object, which is glossy paper. A roller feeder mechanism was used in the paper folding process because it is the most suitable system with high folding speed supported by a simple mechanism. The transmission used employs plastic gears because they are easy to maintain, lightweight, corrosion-resistant, and do not require lubrication. However, in this study there is no information regarding the production capacity.

Furthermore, in the feeder input concept, there is research by Bryan Septiano Christly, Agus Halim, and Agustinus Purna Irawan [10]. The feeder system used to feed cardboard into the cardboard slitter machine includes a stepper motor and air compressor drive system, construction materials using aluminum profiles and steel, power transmission through timing belts and ballscrews, and effector via pneumatic cylinders. The main advantage of this system is its compact shape and ease of mobility due to the wheels on each leg of the machine frame. However, this machine can only be used for one size of cardboard due to deficiencies in the control system and actuators used.

Dwikky's research emphasizes the use of an aluminum friction feeder, which is more affordable and easier to source, and includes a multi-size acrylic support due to its elastic nature. Additionally, a motor is utilized to power the prototype belt conveyor that transports the cardboard to the folding machine. However, this study encountered problems with the friction feeder, such as slippage that damaged the cardboard. To resolve this, the research introduced a smooth rubber component to reduce friction, which led to a production capacity based on testing 40 cartons in 4 minutes [11].

The research by Yuxing Wang and Robert B. Stone highlights the importance of a functional approach in machine design, focusing on productivity. In this study, the developed box folding machine showed a significant increase in output producing 30 boxes per minute compared from just 6 boxes per minute from the manual process. However, the production results obtained do not include information on the speed used to achieve those production results.

In this research, the modular development concept of the feeder has been successfully designed and fabricated. Therefore, the main objective of this study is to design and build input and output feeders with modular approach, followed by performance testing to compare the number of folded cardboard productions at the input and output feeders before development with those that have undergone modular development. Additionally, this testing is expected to meet the list of requirements provided by potential users, such as having an output feeder with a pressing mechanism to prevent folded cardboard from reopening and a semi-automatic cardboard feeding system that reduces the need for operator control.

2. Method

The research method consists of important stages to achieve the research objectives. In this study, these stages refer to the flowchart as a guide for the research steps. Figure 1, shows the flowchart of the research from beginning to end.

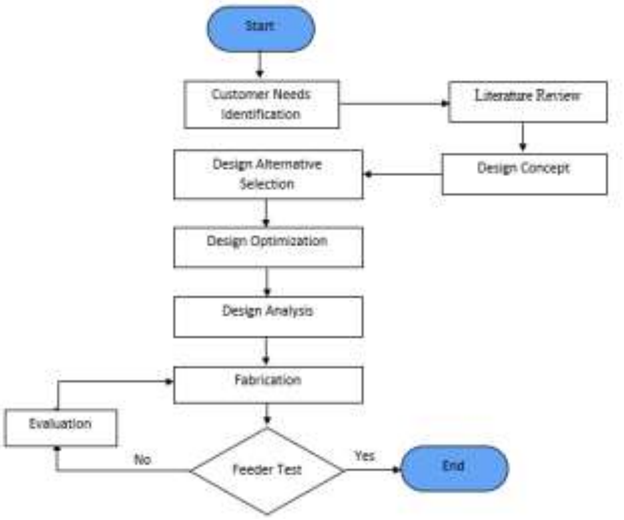

Figure 1. Research Flowchart

2.1 Customer Needs Identification and Literature

Identification of needs for the input and output feeders will be conducted through interviews with packaging entrepreneurs. In addition, an observational study was conducted to validate the results of the previous online interviews, resulting in a list of problems needed by potential users. In the initial design stage, this part plays a role in providing data about the requirements that must be met [12], so the achievement of goals becomes more effective. Typically, this process controls the design during technical design phases. Additionally, observation and surveys are needed to identify customer needs and production requirements. This step is also crucial in the process of formulating design specifications [13].

Literature review is a method of gathering information from reference sources related to the theoretical aspects of a research problem [14]. The collected information can take the form of written content from books, articles, journals, previous studies, and other credible sources. The results of data collection can be used as a reference in creating input and output feeders using the appropriate manufacturing process with reliable machine performance and effective working time.

2.2 Design Concept

After the process of designing specifications based on data collection has been completed, several conceptual designs in the form of sketches will be created. These sketches are temporary and only serve as a medium to pour out ideas [15] and will be compared using a ranking method. Design is based on the results of observations, interviews, and literature studies, so these results will become the key points for the design to be carried out [16]. Considerations investigated after the conceptual design process include several factors, such as ease of operation, minimizing operator effort, integrated modular machine construction, and ease of maintenance.

2.3 Design Alternative Selection

The selection of alternative designs will be carried out as a form of determining the suitable conceptual design to cover the needs of the input feeder and output feeder. There are three concept designs to be determined with various types of mechanisms and structural construction designs. This process begins with analyzing the strengths and weaknesses of the existing machine specifications, then adjusting them to the needs of potential users [17]. Based on the three proposed concepts, one selected concept is chosen through design selection. To determine the suitable concept design, a ranking method is created and used to evaluate each concept design [18].

2.4 Design Optimization

The predetermined design concept will undergo a design optimization process [19]. This process includes sourcing electrical components, determining materials, and mechanical components. Additionally, each aspect of the design concept is explained with a description related to a comprehensive description of the selected design size and materials used.

2.5 Design Analysis

The design will be analyzed through material strength modeling using Finite Element Analysis (FEA) method. Analysis using the simulation method is a much cheaper and more effective approach compared to experiments [20]. With this analysis method, we can determine desired design process variations, which can continue to the design stage. FEA modeling becomes a method that helps optimize the design of a machine and its components before fabrication is carried out [21]. Consequently, this method can generally reduce design costs and time.

2.6 Fabrication

Based on the identified issues, there will be an enhancement of the previously made cardboard folding machine by installing input and output feeders at the beginning and end of the cardboard folding machine. In the fabrication process, the selection of materials and manufacturing processes is crucial to consider. Material selection is a vital factor in this phase because the characteristics and properties of the material can affect the fabrication process of the input and output feeders [22]. Manufacturing process selection is done to find the best fit for each assembly process and design requirements. Several factors need to be considered, including the materials to be used, the number of required components, the size of the product, and dimensional tolerances.

2.7 Feeder Test

Feeder was tested in two stages, including:

a) Functional Feeder Test

Functional testing of the input and output feeders is aimed at comparing our planned design with user expectations. One of the functional tests conducted is based on the machine's performance [23].

b) Geometric Feeder Test

The geometric testing of the input and output feeders aims to test the fabricated feeder geometry and then compare it with the design as well as any size deviations that occur [18].

3. Result and Discussion

Chapter 3 contains the stages that have been carried out to achieve the research objectives based on the research method planned in the previous chapter. The results and discussion of the research are stated in the following subsections.

3.1 Customer Needs Identification and Literature

The identification of needs for the input and output feeders is conducted through interviews with packaging entrepreneurs as shown in figure 2. In addition, an observational study was conducted to validate the results of the online interviews, which can be seen in figure 3. Based on the results of these interviews and observations, a list of problems needed by potential users was obtained, as shown in table 1.

Figure 2. Interview with Potential User

Figure 3. Manual Cardboard Folding Process

Table 1. Needs Identification Results

No	Results of Needs Identification
1	Have a cardboard stacking mechanism that prevents glued cardboard sheets from reopening to its original position.
2	Can minimize the use of operator energy as an effort to save time and costs in packaging operations.
3	Feeder is easy to operate, easy to maintain, and its design process can be done continuously in a modular approach.

According to Maximilian Helmstidter [24] in his patent regarding the friction feeder as seen in figure 4, the suitable feeder for thin materials such as paper or cardboard is using a friction feeder equipped with rotating rollers. The material arranged slowly will pass through the gap of these rollers.

The use of the rollers is prohibited from damaging the quality of the materials or disrupting the cardboard folding process, which could result in the production output not meeting the target. Therefore, the use of nylon rollers is employed in the feeder that has been created because this material is not easily flammable, resistant to damage from water and excessive light, has a smooth surface commonly used in making plastic components, and is strong, making it suitable for mixing in clothing and carpet materials [25].

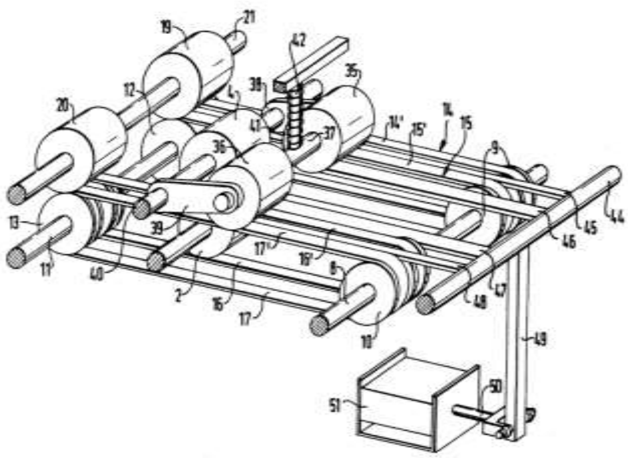

Figure 4. Friction Feeder Mechanism [16]

3.2 Design Concept

Based on the identified needs as seen in table 1, the selection of design criteria is carried out. The design criteria for the input feeder and output feeder can be seen in table 2.

Table 2. Design Criteria Lists

No	Design Criteria
1	Able to separate cardboard sheets one by one toward the created module.
2	Capable of stacking cardboard piles so that the folds of the cardboard, which have undergone the gluing process, do not reopen.
3	Using cardboard dimensions of length 10 cm, width 10 cm, height 10 cm, and thickness of approximately 3 mm.
4	The feeder dimensions are adjusted to the cardboard folding machine that has been created and tailored based on user needs identification.

After the design specification process based on the collected data has been completed, several conceptual designs in the form of sketches are created. These sketches will be compared using a ranking method. The determination of the most suitable design in this study will utilize the decision ranking method. This process is important to determine the configuration and specifications of the intended product [26], such as ease of operation and minimizing operator effort, integrated modular machine design, and ease of maintenance.

The first alternative of the feeder input can be seen in figure 5, using a vacuum feeder mechanism can be more efficient and facilitate equipment integration, but this vacuum-based concept has drawbacks due to more difficult maintenance with limited human resources, so after discussing with the customer, it can be seen in table 3 this alternative has low values in terms of maintenance aspects, operating methods, and operator capabilities.

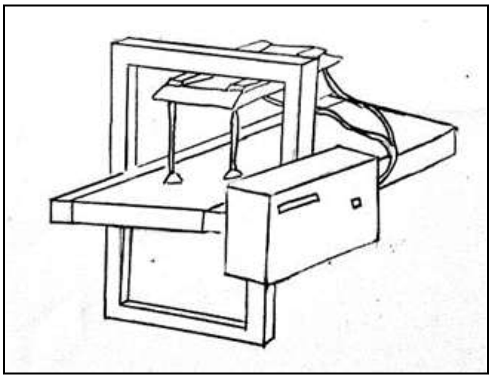

Figure 5. Alternative Feeder Input Design 1

The second alternative of the feeder input can be seen in figure 6, using a friction mechanism. This concept is the selected sketch alternative because it is easy to operate, with the operator only needing to stack cardboard and turn on the conveyor at the feeder, then the cardboard will pass through one by one. Maintenance and tool integration are not as difficult as the other two concepts, as seen in table 3.

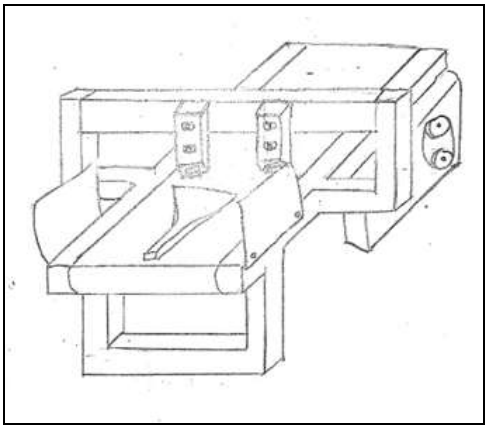

Figure 6. Alternative Feeder Input Design 2

The third alternative of the feeder input can be seen in figure 7, using a shuttle feeder mechanism with pneumatic as the driver. The integration value of this concept is rated as 2 as seen in table 3 because with the use of this concept, the input module of this cardboard folding machine is completely overhauled and the efficiency of the concept is also questioned when the operator has to press the shuttle button from the pneumatic every time the cardboard has to be directed to the conveyor, and the maintenance aspect associated with this concept.

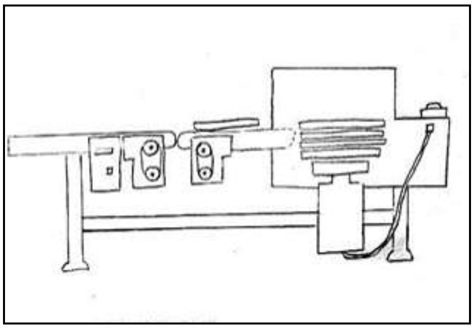

Figure 7. Alternative Feeder Input Design 3

In addition to the sketch of the feeder input, there are also sketches of the feeder output consisting of 3 alternatives. The first alternative of the feeder output can be seen in figure 8 uses a servo as the driver, but in terms of modular concept, alternative 1 completely changes the overall construction of the feeder because it eliminates the output module in this concept. This becomes a drawback in terms of human resources when the tool is used regularly as seen in table 4.

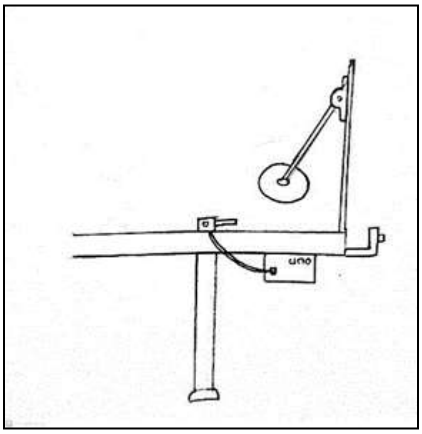

Figure 8. Alternative Feeder Output Design 1

The second alternative of the feeder output can be seen in figure 9. This concept is the selected alternative of the feeder output concept, featuring an adjustable angle pressing wheel system. This concept provides flexibility for folded cardboard to prevent it from reopening with a larger quantity of cardboard, thus receiving a modular concept rating according to the user's preference, rated at 5 as seen in table 4.

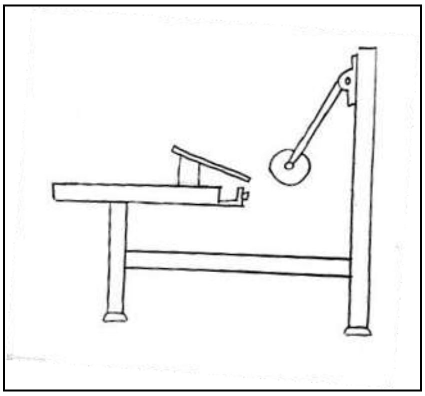

Figure 9. Alternative Feeder Output Design 2

The third alternative of the feeder output can be seen in figure 10. The use of this concept is almost similar to the second concept, but when the cardboard sheets come out of the conveyor without any pressing part at the end, then this concept is not better than the second concept, so the value of the modular concept implementation is not as high as the second concept as seen in table 4.

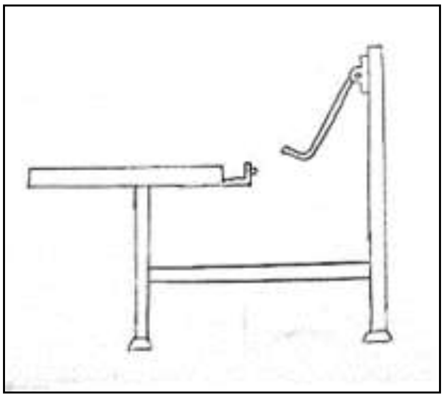

Figure 10. Alternative Feeder Output Design 3

3.3 Design Alternative Selection

The selection of design alternatives is done as a form of determining a conceptual design is suitable to cover the needs of the feeder input and feeder output modules. There are three conceptual designs, each of which will be determined by the type of mechanism and diverse structural design. Based on the three proposed concepts, one selected concept will be chosen through a joint design selection with potential users. To determine the suitable conceptual design, a ranking method is created and used to evaluate each conceptual design. The most suitable design alternative will be determined using a decision-ranking method. The selected design will proceed to be modeled in a 3D technical design using a CAD system.

In table 3, it shows the assessment results for the 3 alternatives of feeder input, using a scale of 1-5. Where 1 means very poor and 5 means excellent. Therefore, the second sketch design alternative is chosen to be continued to the next stage.

Table 3. Feeder Input Ranking Method

Feeder Input			
Criteria	**Alternative1**	**Alternative2**	**Alternative3**
Easy to Operate	3	5	3
Modular Integration	4	5	2
Efficiency	3	3	2
Maintain	3	4	3
Production Cost	2	4	3
Total Score	15	21	13

In table 4, it shows the assessment results for the 3 alternatives of feeder output, using a scale of 1-5. Where 1 means very poor and 5 means excellent. Therefore, the second sketch design alternative is chosen to be continued to the next stage.

Table 4. Feeder Output Ranking Method

Feeder Output			
Criteria	**Alternative1**	**Alternative2**	**Alternative3**
Easy to Operate	4	4	4
Modular Integration	2	5	5
Efficiency	4	4	3
Maintain	3	4	3
Production Cost	3	3	4
Total Score	16	20	19

3.4 Design Optimization

After selecting the design sketches for the feeder input and feeder output, the next step involves developing more detailed designs. This development includes determining dimensions, types of materials, FEA analysis, as well as identifying the mechanical and electronic components needed. It can be seen in figure 11, which is the three-dimensional realization of the conceptual sketch design of the feeder input that has been created in the CAD System. The component descriptions in figure 11 can be seen in table 5.

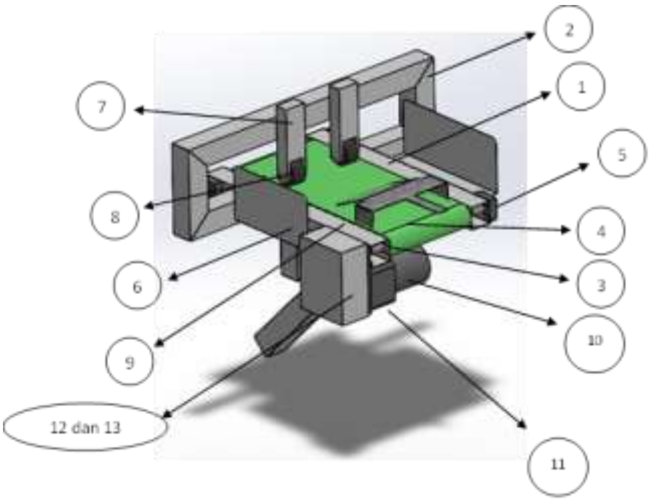

Figure 11. Feeder Input Final Design

Table 5. Feeder Input Component

No	Component	No	Component
1	Main Frame	8	Friction Roller
2	Friction Frame	9	Input Plate Cover
3	Roller Conveyor	10	Drive Motor
4	Belt Conveyor	11	Gearbox
5	UCFL Bearing	12	Sprocket
6	Retainer Frame	13	Gear
7	Friction Rod		

The realization of the feeder output sketch was also made in its three-dimensional version using the CAD system as seen in figure 12. The component descriptions in figure 12 can be seen in table 6.

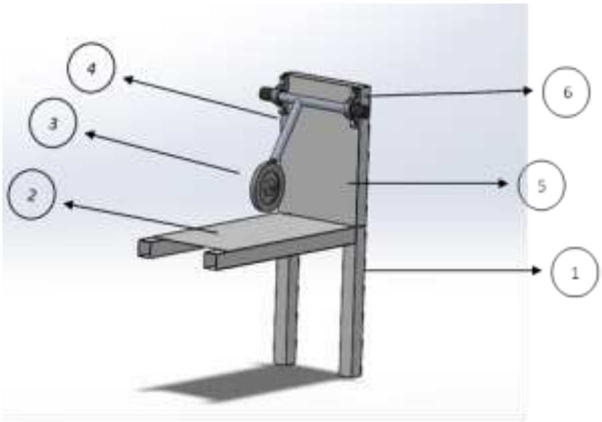

Figure 12. Feeder Output Final Design

Table 6. Feeder Output Component

No	Component
1	Feeder Output Frame
2	Storage Plate
3	Pressing Roller
4	Bar Roller
5	End Plate
6	UCP Bearing

3.5 Design Analysis

Before the fabrication process, essentially when the design has been optimized, it would be more effective to conduct further simulation processes to test the reliability of the frame will bear the load [3]. In this case, simulation is carried out on the static loading of the frame, commonly known as Computer Aided Engineering (CAE), to demonstrate whether the frame is strong enough to withstand the given loads. This is done by determining the placement of loads at several points on the frame and defining the support points using solidworks software. The loads applied are adjusted according to the loads carried by the feeder input and feeder output, using galvanized steel as the material. The load for each part in the simulation is determined using the loading menu in solidworks and validated through weighing the parts before fabrication, as well as data from previous literature studies.

Based on the data in table 7, it can be seen the weight of each component will be included in the feeder input frame is 29.8 kg. Each weight and quantity data was obtained through a literature study, weighing process, and interviews conducted with relevant parties.

Table 7. Feeder Input Loads

Part Name	Weight	Quantity	Total Weight
Cardboard	42 gr	500	21 kg
Roller	1.5 kg	2	3 kg
Motor and Gearbox	1.8 kg	1	1.8 kg
Sprocket	250 gr	2	500 gr
Cover Plate	500 gr	1	500 gr
Friction Frame	3 kg	1	3 kg
Total			29,8 kg

Furthermore, Based on the data in table 8, it can be seen the weight of each component will be included in the feeder output frame is 21,85 kg.

Table 8. Feeder Output Loads

Part Name	Weight	Quantity	Total Weight
Cardboard	42 gr	500	21 kg
Storage Plate	850 gr	1	850 gr
Total			21,85 kg

Analysis of the feeder input strength is given a load of 29.8 kg with values as listed in table 7. Based on figure 13, the highest stress point with a value of 14.863 MPa is obtained due to the stress experienced from the original condition caused by the given load. Since this value is smaller than the yield strength value of the material, which is 203.943 MPa, it can be said the frame can withstand the load well [27].

The value is validated through mathematical calculations to find the maximum stress on the hollow frame by considering the bending moment value obtained, the distance to the center of gravity, and the inertia magnitude of the material. Based on the mathematical validation process [28], a value of 15,48 MPa is obtained.

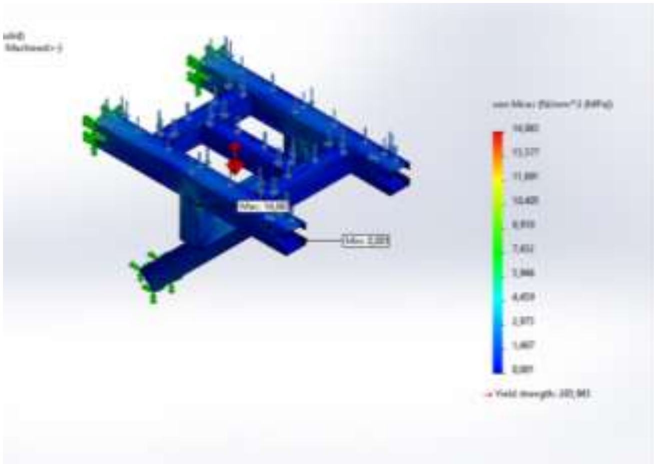

Figure 13. Maximum Stress Feeder Input Frame

Analysis of the feeder output strength is given a load of 21,85 kg with values as listed in table 8. Based on figure 14, the highest stress point with a value of 14,059 MPa is obtained due to the stress experienced from the original condition caused by the given load. Since this value is smaller than the yield strength value of the material, which is 203.943 MPa, it can be said the frame can withstand the load well. Mathematical validation was conducted for the maximum stress calculation, with the obtained value being 14.53 MPa.

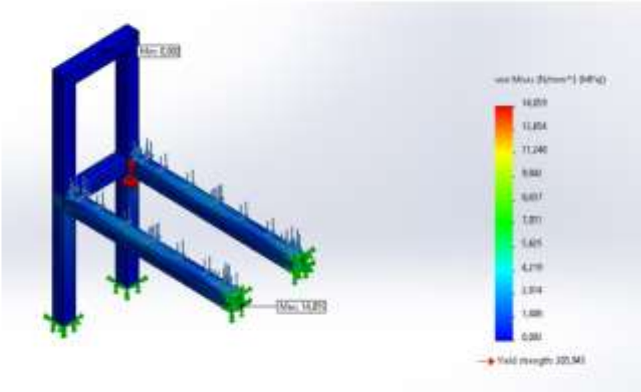
Figure 14. Maximum Stress Feeder Output Frame

3.6 Fabrication

Before proceeding to the fabrication stage, first purchase all the materials needed for making the feeder input and feeder output. The materials needed include 5 x 5 cm hollow iron rods with a length of 6 meters, totaling 3 rods, roller conveyor for the feeder input with details of 22 mm width and 50 mm diameter, handling shafts left and right 5 cm and diameter 18 mm, belt conveyor with length ≥1157 mm, thickness 3 mm, width 22 cm, 200 x 200 cm iron plate, pressure roller with a diameter of 100 mm.

The use of a frame with hollow iron is done because this feeder input and feeder output will be integrated into the folding conveyor of the cardboard folding machine, also developing modules of the cardboard folding machine to fit the desired modular concept for users. To facilitate the installation process between modules, a non-permanent connection using nuts and bolts was chosen to join the modules. The fabrication results of the feeder input can be seen in figure 15 and the fabrication results of the feeder output can be seen in figure 16.


Figure 15. Feeder Input Fabrication Result


Figure 16. Feeder Output Fabrication Result

Table 9. Feeder Input Engineering Diagram

No	Description	Before Modular Development	After Modular Development
1	Feeder Input Shape		
2	Feeder Weight	40 kg	64 kg
3	Feeder Width	320 mm	670 mm
4	Feeder Mechanism	Manual	Motor with Friction Feeder
5	Feeder Control	Manual	Motor Controller
6	Speed	Adjusting the operator's hand speed	Max 127,5 rpm
7	Resources	Manual	Motor power 25 W
8	Modul Connection	 Bolts and Nuts	 Supporting Frame

In table 9, there are several changes to the feeder input made with a modular approach and adjusted to user preferences, such as the process of manually inserting cardboard by operators being changed to using a conveyor belt with a friction feeder mechanism along with a driving motor. The use of workers is not eliminated in the concept after development, they can still act as operators because this mechanism requires workers to stack cardboard that will be fed into the friction mechanism. Weight difference between these two mechanisms; the module after development is heavier than before development due to the drive for the friction mechanism. The width is also different; the module after development is wider due to the presence of the supporting frame for the friction mechanism. The connections in the module after development use a supporting frame to better withstand the load from the components and reduce vibrations during the production process.

Table 10. Feeder Output Engineering Diagram

No	Description	Before Modular Development	After Modular Development
1	Feeder Shape		
2	Feeder Weight	30 kg	38 kg
3	Feeder Width	320 mm	320 mm
4	Feeder Mechanism	Manual	Pressing Roller
5	Feeder Control	Manual	Roller Inclined
6	Speed	-	-
7	Resources	Manual	Manual
8	Modul Connection	 Bolts and Nuts	 Bolts and Nuts

In table 10, there are changes in the feeder output made with a modular approach and customized to user preferences, such as the output process of the cardboard which initially often reopened after folding. With the presence of the cardboard fold-pressing wheel mechanism, it can be pressed while waiting for the curing time of the folded conveyor and adhesive results. Weight difference between these two mechanisms; the module after development is heavier than before development due to the presence of a pressure wheel. Both mechanisms have the same width. The module connections use nuts and bolts to facilitate easy installation and disassembly between modules.

3.7 Feeder Test

Testing will be conducted on the feeders that has been fully built. There are two tests conducted for this input feeder and output feeder. The first test is a functional test to compare the performance of each feeder before and after development to ensure it aligns with the user's desires. The second test is a geometric precision test.

In table 11, a comparison can be seen between the process of manually inserting cardboard into the input module as shown in figure 17 and through the development of a modular concept with a friction feeder mechanism as shown in figure 18. Functional testing was conducted with two conveyor folding speed variations,at 80 rpm and 100 rpm. The speed determination was adjusted with motor controller present on the folding conveyor. Additionally, there is variation in the time each cardboard fold will achieve, ranging from 1 minute to 5 minutes. Functional testing is conducted from the input feeder through the folding conveyor to the output feeder (one work cycle). Based on table 11, it can be concluded using the feeder input makes the cardboard folding machine work process more efficient in terms of time and labor compared to using the manual concept from the previous development.

Table 11. Cardboard Folding Machine Functional Test Result

Number of Cardboard Folds (pcs)		
	80 RPM	
Time (sec)	Fold Before Development (pcs)	Fold After Development (pcs)
60	12	20
120	25	39
180	34	55
240	47	80
300	58	92
	100 RPM	
Time (sec)	Fold Before Development (pcs)	Fold After Development (pcs)
60	16	34
120	32	54
180	51	88
240	68	102
300	87	117

Figure 17. Manual Cardboard Input

Figure 18. Feeder Input After Development

Table 11 shows the results of tests conducted with variations in the conveyor motor rotation speed, controlled through a motor controller with 80 rpm and 100 rpm. Performance test started at 60 seconds and its multiples up to 300 seconds, measured with a stopwatch. Based on the data from the table, each can be explained one by one through graphs referencing the speed variations below.

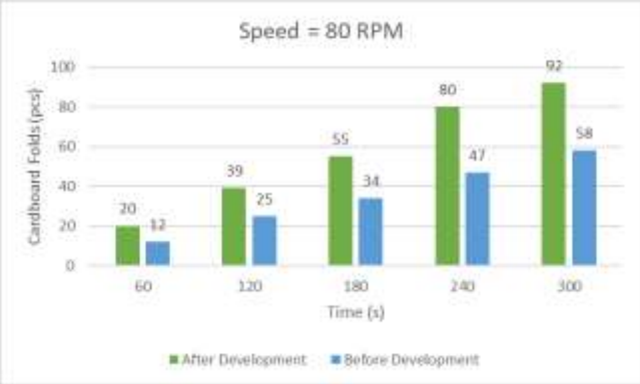

Figure 19. Cardboard Folding Result at 80 RPM

Based on figure 19, at 80 rpm feeder input with friction mechanism has a higher initial insertion point for cardboard, with a difference of 8 sheets of cardboard compared to the manual mechanism before development. This occurs because the initial point for inserting cardboard sheets can enter through the gap between the friction mechanisms, unlike the initial point of the pre-development mechanism that requires operator control. However, the friction mechanism experiences a decrease in the production of cardboard sheets between the time ranges of 120 to 180 seconds and 240 to 300 seconds. This happens because the stack of cardboard needs to be refilled by the operator when it reaches the maximum stack capacity of 40 sheets and its multiples, as illustrated in figure 20. Therefore, at this speed variation, the friction feeder mechanism after development results in better production efficiency of cardboard folding at 80 rpm compared to the input feeder mechanism before development.

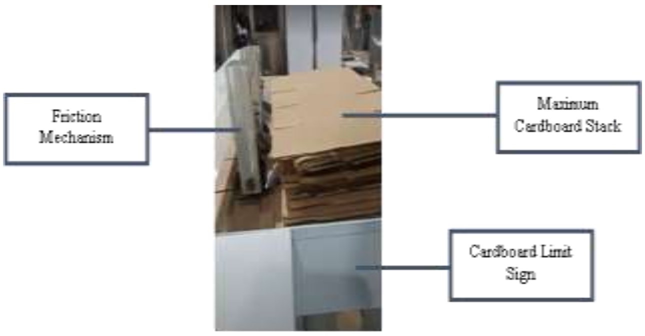

Figure 20. Cardboard Stack Limit

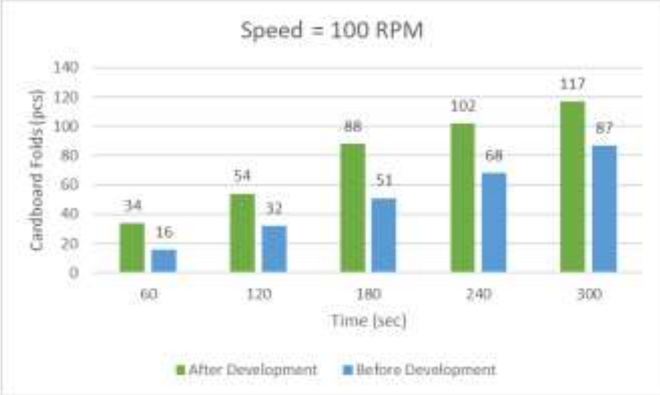

Figure 21. Cardboard Folding Result at 100 RPM

Based on figure 21, at conveyor motor speed variation of 100 rpm, it is observed the pre-development input feeder mechanism shows a more orderly increase in the number of folded cardboard produced. Although it is less efficient compared to the friction mechanism, the cardboard folding activity can be thoroughly monitored by the operator, reducing the likelihood of bottleneck or obstructions in each process.

In contrast, although the initial output of the friction mechanism results in more than twice the number of folded cardboard compared to the pre-development input, this mechanism experiences bottlenecks, usually due to limitations in resources such as technology or labor , which restrict the production system's capacity [29]. When the speed variation reaches 180 to 240 seconds and 240 to 300 seconds, it causes a queue of cardboard sheets waiting to be folded. This issue arises because the length of the folding conveyor is not suitable for handling a large production volume at one time. As a result, within this time range, the number of folded cardboard does not reach the expected amount, only increasing by 14-15 pcs. This congestion can be seen in figure 22.

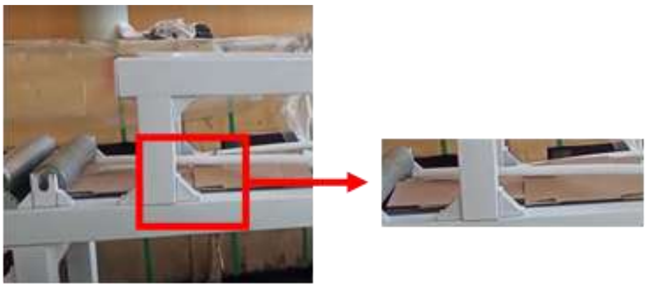

Figure 22. Bottleneck in Folding Conveyor

Based on previous research conducted by Wang, this corrugated box folding machine produced 30 cardboard sheets within a one-minute timeframe with an unspecified speed. Furthermore, in research conducted by Dwikky, the folded results of cardboard food boxes with the feeder reached only 40 cartons in 4 minutes, whereas 10 cartons were folded in 1 minute. Therefore, the output from the modularly developed input feeder shows better results compared to several previous studies, with 34 folded cardboard sheets in a initial point duration and a speed variation at 100 rpm.

In addition, there has been a significant development in the feeder output section related to the cardboard sheet pressing process that has been folded. This can be seen in figure 23, when the cardboard output is still done manually, the folds of the cardboard output from the folding conveyor change back to their original shape because there is no mechanism to press these cardboard folds. However, with the presence of a pressing roller in the modular development as seen in figure 24, the folds of the cardboard that have come out of the folding conveyor do not reopen because they have been pressed by the pressing roller.

Figure 23. Manual Cardboard Output

Figure 24. Feeder Output After Development

The next test is geometric testing by comparing the input feeder size and the fabricated output size with the desired design size. As shown in table 12 and table 13 explained there are differences in the frame size of the finished input and output feeder compared to the design, with some parts not entirely matching the design in the software. These differences are due to the cutting process during fabrication.

Table 12. Feeder Input Geometry Test Result

Component Name	Dimensions (mm)	
	Design	Finished Product
Main Frame	500	500,2
Friction Frame	660	660
Friction Rod	200	200

Table 13. Feeder Output Geometry Test Result

Component Name	Dimensions (mm)	
	Design	Finished Product
Main Frame	690	690
Storage Plate	500	500
End Plate	420,4	420

4. Conclusion

Based on the results from the previous explanation, it can be concluded the input and output feeders have been successfully designed with a modular approach. Functional testing analyzing the performance of the input feeder before and after development in one cycle shows improvements in every speed variation tested. At a conveyor motor speed of 80 rpm, the difference in folding results between the developed feeder and the previous one varied; at the 60-second time range, there was a difference of 8 folded cardboard sheets, which increased over time, reaching a difference of 34 sheets at the 300-second range. Similarly, at a conveyor motor speed of 100 rpm, the difference in folding results in the initial output was 18 sheets, increasing to 30 sheets by the final time variation. Although the input before development had a lower production value compared to the input mechanism with a friction feeder, the increase in production that occurred in the input before development was more consistent because an operator was in control of the input process. Feeder after development production was better, but at certain time variations the increase was not optimal because the operator had to refill the stack of cardboard and bottleneck issues caused a queue in the folding process. In addition to comparing the performance testing between the developed modules, improvements over previous research were also noted. By comparing the cardboard folding production results from the developed feeder with other studies, it is found the production improvement achieved in this study is better than the production results from other studies.

The modular concept also meets the list of requirements provided by prospective users, including construction dimension consistency, cardboard dimensions, material used, and manufacturing process of module connections without welding, which facilitates installation. User feedback on the development of a semi-automatic input feeder, which reduces operator work time, has been achieved; operators who previously manually folded cardboard now only need to load the stacks into this system. Other achieved requirements include the output feeder, which also reduces the operator's work duration and now controlled by a pressure wheel. This study has shortcomings regarding the analysis of the quality of the obtained cardboard as well as the analysis of issues such as bottlenecks that occur. Therefore, continuous analysis of the cardboard folding machine system is needed, whether through the development of new versions or improvements to existing versions, to create the best version of the cardboard folding machine system.

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