FACULTY OF ENGINEERING AND APPLIED SCIENCE

ENGR 4280U

Robotics and Automation

Robot Work Cell Area

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Objective

The project emphasizes the importance of concept generation and design of a robot work cell that follows CSA standards and is able to fit in an existing robot to palletize boxes.

Scope

The requirement for this project is to design a robot work cell capable of allowing a robot to palletize cardboard boxes, weighing 10 kg each, while adhering to safety standards CSA Z434 and CSA Z432. The boxes will be unloaded from a conveyor belt onto empty wooden pallets which will be delivered to the customer. The dimension of the pallets and boxes are 48” x 48” x 6” and 24” x 12” x 8” respectively (Length x Width x Height). The boxes are to be stacked in 6 layers with 8 boxes occupying an individual layer. The orientation of each layer will alternate from the previous to provide stability during transportation. The robot work cell must abide by CSA Z434: Industrial Robot and Robot System and CSA Z432: Safeguarding of Machinery . The standards ensure safety measures and practices are applied throughout the robots operation to protect the surrounding individuals and machinery from harm. The robot work cell design should allow the robot to work efficiently, be compact, cost effective and follow safety measures.

Requirements

The customers require a robot work cell that allows a robot to palletize cardboard boxes stacked in 6 alternating layers that adheres to safety protocols, are compact, cost effective and can perform the work in a short amount of time. To accomodate for the customer requirements a list of customer needs and wants were identified below [1] [2]:

Customer Needs

- Sturdy robot work cell that allows a robot to complete the objective successfully
- Robot work cell that is economical

- Robot work cell that has safety designs implemented to protect workers
- Robot work cell that does not consume much space
- Robot that is economical
- Robot that is able to palletize 10 kg boxes in the shortest time possible

Customer Wants

- Robot that has many degrees of freedom
- Robot work cell that allows a robot to change its end effector to perform other tasks if required
- A mobile robot work cell that is mobile and lightweight
- Robot work cell that is easy to assemble, disassemble and repair if needed
- Robot work cell is made of parts that are easily obtainable and quick to deliver

The customer is in need of a robot work cell that is economical, sturdy, has safety systems installed, does not consume much space and allows the robot to complete its task successfully. Depending on the use of the robot cell, a single robot work cell is priced similarly to a new car ranging from $35,000 to $75,000 [3]. The cost is dependent on the following factors:

- Robot selected to complete the job
- End effector
- Installation and Operation cost
- Maintenance
- Availability of parts
- Safety guards installed

Since the boxes are 24” x 12” x 8” (609.6 mm x 304.8 mm x 203.2 mm), the most appropriate end effector to use is a clamp gripper. A clamp gripper is ideal for applications that involves heavy equipment or lifting packages that has an irregular shape on the top. The disadvantage to using a clamp gripper is the need for consistent maintenance. Since the box is considered to be moderately heavy the clamp gripper was chosen as the end effector. Other end effectors considered were a vacuum and finger gripper end effector. A vacuum end effector is the least expensive type of gripper available on the market. The disadvantage to a vacuum gripper is a higher operating cost and a drop in performance when operating in dirty environments. Finger gripper end effectors were another possible choice that was considered. A finger gripper combines the advantages of a clamp and a fork gripper. The issue with the finger gripper is a need for special equipment to operate [4] [5]. Since the clamp gripper is sufficient in palletizing boxes, a finger gripper would be considered a luxury to spend. The frequency for maintenance on the robot work cell is considered to be low. Since the robot is only palletizing boxes it is assumed that not much maintenance will occur aside from cleaning the work cell. Off-the shelf components will be used for the robot work cell which includes a conveyor belt, light sensor and fences. Using parts that are readily available reduces loss of productivity waiting for the part to arrive.

Customers want a robot work cell that is easy to assemble, disassemble and repair if needed. In addition, customers want a robot to change end effectors within the robot work cell. These requirements are not considered mandatory since they do not contribute in helping the robot complete its main objective. Nonetheless, consideration has been made to accomodate for the customers desired features and will be analyzed further within the report.

In addition to the customer requirements, the robot work cell will be designed in a way that complies with the safety standards and procedures listed in CSA Z434, CSA Z432, ISO 13857 and many others.

Background Research

Background Research #1

BACKGROUND

An Automatic palletizing system, which has the ability to assess and determine the ideal arrangement of a pallet, without any information of the boxes to be provided to the system [7].
*Note: The “Automatic palletizing system” will be referred to as the “invention” henceforth.

ABSTRACT

The invention possesses the ability to pre-determine the configuration of the pallet, prior to any knowledge of the boxes to be loaded. The invention can manage different sizes and weights of boxes to be loaded. The process involves the utilization of a conveyor belt to pass boxes to the pre-determined optimally arranged pallet to extract raw data of each box. The data extracted encompasses weight, dimensions, and contents through the use of a weighing, dimensioning, and scanning station respectively. The pallet arrangement is automatically adjusted using a processor, which analyzes the current arrangement data, to generate an ideal configuration for the possibility of boxes to be loaded. The involvement of queuing station is implemented in the design, to readjust the sequence of the boxes to be loaded, for the finishing pallet arrangement under direct control of the processor. In addition to regulating the queuing station, the processor also manipulates a robot arm to load boxes onto the pallet [6].

BACKGROUND OF THE INVENTION

1. Field of the Invention

Fundamentally, the invention serves the purpose of automatically loading boxes of different sizes and weights on a pallet, optimally configured using a processor, without any information of the boxes to be loaded.

2. Description of the Prior Art

2.1 Prior technology does not encompass the inclusion of a processor to pre-determine the optimal configuration of a pallet with boxes of different sizes and weights.

Pros: Technology involved the use of loading boxes manually onto a pallet.

Cons: Implications of prior technology are possibility of injuries and high labor costs.

i) Prior technology of the invention involves managing boxes of the same size such as:

a) Henderson U.S. Pat. No. 4,786,229: "Document storage and retrieval apparatus method" [7]

2.2 Advancements in technology include automating the system to manage loading boxes of different sizes and weights onto a pallet. These advancements can be classified into two sectors:

i) Operator is equipped with prior knowledge in terms of the specifications of the boxes to be loaded. Incorporating strategies such as a graphic terminal, an operator is capable of programming the computer in regards to the placement of each box onto the pallet. Based on the pre-determined placement of each box, the computer is able to assess the optimal arrangement for the boxes to be loaded onto a pallet. Subsequently, boxes to be loaded are displaced using a regulated robot arm. Prior technology of the invention includes:

a) Konishi et al. U.S. Pat. No. 4,641,271: "Piling planning method and piling system of cargoes by palletizing robot" [8]

b) Tenma et al. U.S. Pat. No. 4,692,876: “Automatic freight stacking system” [9]

c) Roccabianca et al. U.S. Pat. No. 4,746,255: “Machine for automatically loading pallets” [10]

Pros: This technology involves an operator to have prior knowledge regarding the requirements of the boxes to be loaded onto the pallet, and must define the arrangement of the pallet.

Cons: Implications of prior technology are possibility of human error in the optimization process.

ii) Expert System is equipped with prior knowledge in terms of the specifications of the boxes to be loaded. Implementation of an expert system to assess and define the arrangement of a pallet for different weights and sizes of boxes.

a) “An Expert System Approach to Palletizing Unequal-sized Containers,” Gilmore et al., SPIE Application of Artificial Intelligence, March 1989

b) "Palletizing Unequal-Sized Containers,” Gilmore et al. Proceedings of SPIE, March 1989

Pros: This technology involves the system to automatically define the arrangement of a pallet for various boxes with different specifications with the condition that the system has prior knowledge of the specifications.

Cons: Implications of prior technology are possibility of system error in the optimization process.

3. *Advantages & Disadvantages*

Pros: The invention possesses the ability to a) handle different weights and sizes, b) automatically define the arrangement of a pallet for various boxes with different specifications, c) reduce the possibility of injuries, labor cost and human error significantly.

The invention does not d) require prior knowledge regarding the specifications of the boxes e) involve the process of loading boxes manually onto a pallet.

Cons: The invention may fail due to the possibility of expert system error. It is possible that the reconfiguration of the pallet does not turn out to be the ideal configuration when checked. This can be due to a defect in the processor or the queuing module. If there is an error in the queuing sequence, there is a possibility that the pallet would be composed of boxes positioned in the incorrect places. If the processor is defective, than that would disrupt the flow of the queuing module, repetitive mapping of optimal loading, or the functionality of the robot arm.

SUMMARY OF THE INVENTION

The invention automatically delivers the ideal arrangement of a pallet, capable of loading any size or weight of a box onto the pallet, and does not require prior specifications regarding the boxes. The integration of a conveyor belt enables the transfer of boxes from the loading stage to the unloading stage. The unloading stage involves moving a box from the conveyor to the pallet using a controlled robot arm. As the box along the conveyor, a scanner is used to assess the weight and size of the box. The system's processor analyzes the raw data of the box and the current pallet configuration and generates the optimal configuration of the pallet for other possible boxes to be loaded. Based on the optimal configuration of the pallet, the system's queuing module queues the boxes placed on the conveyor in the appropriate sequence to match the predetermined output. In accordance with the queuing module, the processor controls the robot arm to unload the box from the conveyor and load it onto the pallet.

The reconfiguration of the pallet is accomplished with the assistance of an expert system. This system involves following a weight management procedure, placing boxes that are heavy at the bottom and boxes that are light at the top. Layers of pallets are constructed based on this strategy, instead of forming columns. Thus, boxes are queued in sequence based on the size and weight so that they can be placed in the appropriate pallet. Once a pallet is complete and can load no more boxes, a new pallet is prepared for the possibility of loading more boxes.

For a brief description on the concept drawings please refer to Appendix A.

Background Research #2

The robotic palletizer cell and the method of its construction involves robotic palletizing cells, where the components are stacked by robots.

“ Note: the ‘ Robotic Palletizer Cell and Method Of Construction” will be referred to as the “invention” henceforth

ABSTRACT

The invention involves a palletizer cell encompassing square platform bases that are assembled into an array in support with each other. Every platform base is used for mounting a corresponding component of palletizing equipment, like one or more conveyors, robot, a slip sheet bin, discharge module, etc[22]. One of the platform base is attached to the factory floor and the rest connected to one or another of the platform bases which is used to form the array of platform bases. This makes it easier to locate various equipment with each other by fitting together of the platform bases. Safety is ensured through the use of safety fencing, used as they are mounted onto one or more outer sides to essentially cover the workplace within the palletizer cell [22]. Every platform base is composed with openings on the side that may be engaged with the tines of a forklift.

BACKGROUND OF INVENTION

Palletizing in past has been usually been done by dedicated automation equipment. This particular invention involves constructing a robotic palletizing cell, where the robots will stack items. To achieve robotic palletizing, the initial steps involve custom designing the appropriate layout of the individual pieces of equipment [22]. These consist of the robot, conveyors, pallet stacks etc. It then locates individual equipment on the factory floor in the proper position. Moreover, all the equipments have to be custom engineered and installed with the applicable positional relationship to one and another [22]. This process proves to be time consuming and costly as there is more time required to design, build and install a palletizer cell is considerable. There have been efforts made towards building standardized elements of the the equipments that are needed. However, they have been inadequate in their ability to be used for several applications as the elements would have to be set up in a different manner [22].

The goal of present invention is to implement an equipment and method of pelletizing cell which is quicker and cheaper to design, build and installed than the previous palletizing systems. This can be implemented by condensing the need for individually locating every item of equipment in the installation process. Some of the advantages and disadvantages of this invention are:

Pros: This particular invention a) includes safety fencing to enclose the cell, b) platform bases doesn't have any equipment mounted, to have an open clearance space to allow the robot to function freely within the cell, c) the installation of the cells is simplified as the robot module is bolted on the floor and the rest modules are anchored as they are connected to the robot module[22].

Cons: the invention may fail due to the possibility of multiple system components failing: a) the functionality of the robot arm as a result of flawed logic, b) defective conveyor, c) faulty wiring, d) incorrect dimensioning [22].

SUMMARY OF INVENTION

The robotic palletizer cell incorporates rectangular, preferably square, platform bases of a uniform overall size. This must be adapted to be kept in contact with one and other by attaching connector plates [22]. At least one platform base has to be anchored to the factory floor. The platform bases are made to fit together which helps to locate individual equipment that has been mounted to the platform bases. This is done by assembling the platform bases into an array of modules on the factory floor. Platform for a robot module base is anchored to the floor by lag bolting projecting angled channel pieces [22]. An array is formed by putting together remaining platforms. Connecter pieces overlap with abutting portion of every platform base to hold the array together. This causes the other platform bases to be indirectly anchored to the floor by the connection to the anchored platform base [22]. Also, if desired, platform bases can be anchored to the floor. Platform bases of the robot module and the other module are mounted together in the array to be held in a predetermined spatial relationship. The composition of a platform base includes thick steel plate reinforced above ground. Some of the modules that are provided are:

- a single or a double feed conveyor
- a pallet module
- a discharge module with a chain conveyor for discharging loaded conveyors
- a single or a double product feed conveyor

Each of them are mounted to an associated platform base. There can be two different forms of platform bases, one of them is a solid square which forms a part of the given modules. Also a build module which is composed of a large opening which extends into one side to construct a U-shape while also maintaining the comprehensive size, and the square shape of the first form of platform base [22]. This allows to load a pallet disposed precisely on the plant floor for both opening or for receiving a stack of pallets that would be examined by a robot. The upper surface of the top plate of every platform base are machined with tapped hole patterns [22]. This allows to attach connector pieces and mounting of uprights that supports safety screens along each platform base. This access to the interior space of the palletizer cell is limited. There are several configurations that modules can be arranged in by assembling platform bases in unique positions within the array [22]. This helps to decrease the engineering development which is crucial by the use of standardized parts, essentially lowering the cost that they are provided at.

Design Plan/Project Management

The robot work cell is becoming increasingly popular for use in factories and businesses. The key components to fulfill the customer requirements in a robotic work cell for palletizing is the robot, light sensors, conveyor belts and safety fences. Generally, a robot is defined as an electric mechanical tool led by electronic programming, Also, this robot is able to make the tasks by itself. Therefore, for the robot work cell palletizing applications, the robot may be built by having gantry robot, either 3 or 4-axis. Usually, the robot work cell consists of a 4 axis gantry robot, however, it may be built by even more than 4-axis, according to what it will be the final design of the robot work cell. To make the picture much clearer, the robot work cell palletizer is consisting different components together, such like the infeed-conveyors that deliver products to the robot, at the point the product reach to the robot, there are sensors, which make the product stop at that point, and after the robot palletizer pick and place it to specific point that has been chosen. Also, outfeed-conveyors which take the pallets with all packages away from the robot. Moreover, it contains pallet dispensers which automatically carry each pallet to the robot from a package of pallets. It contains auto slip sheet and safety devices such fences.

The time required to build a robot workcell is dependent on the amount of time required to build the robot, how many workers are involved to create the robot work cell area, and whether components being used are simple or complex. For the robot work cell, it is estimated that a mechanical engineer, electrical engineer, designer, and project manager is required to make the robot work cell design successful. As well, it is assumed that 45 to 50 days will be required to design the robot work cell area. This robot work cell will have numerous off-the shelf components that are needed to be purchase, hence, it may cost around $35,000 to $75,000 overall to build the robot work cell.

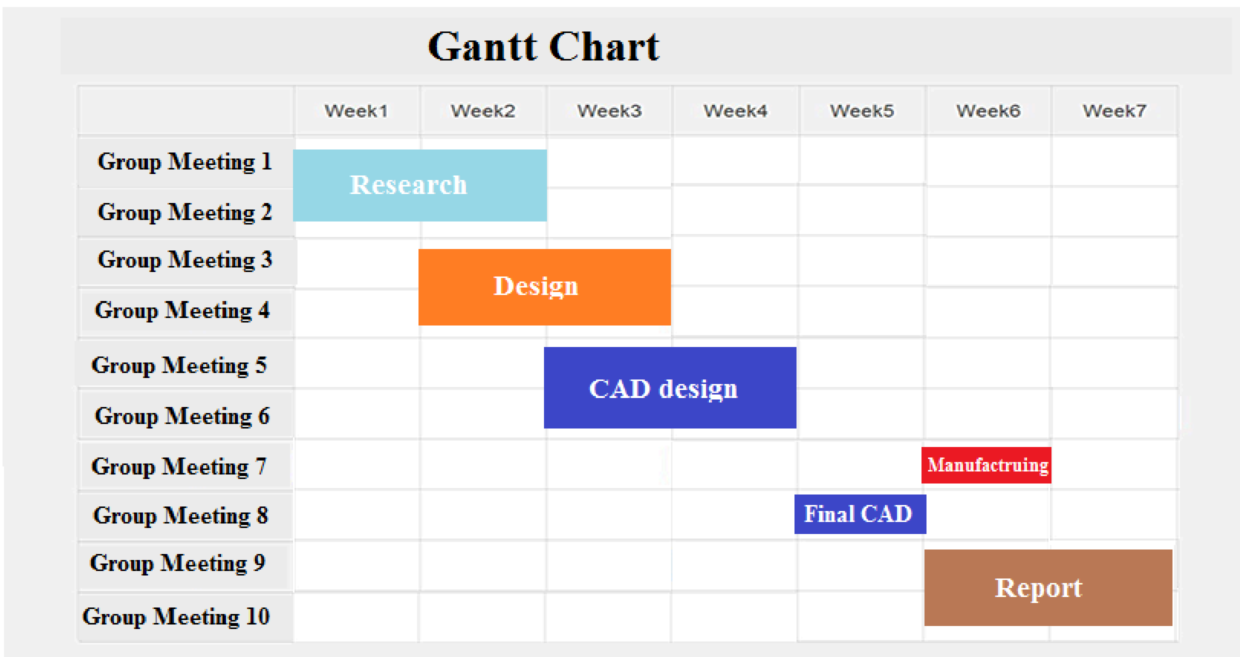


Figure 1: Gantt Chart

Through this project, there are few issues that may be faced when building the robot work cell. One of the main issues is time conflicts between workers. Most workers have their schedules filled with other projects to work on. In order to ensure the robot work cell is built on time a Resource Calendar will be used to track the workers time spent on the project as shown below.

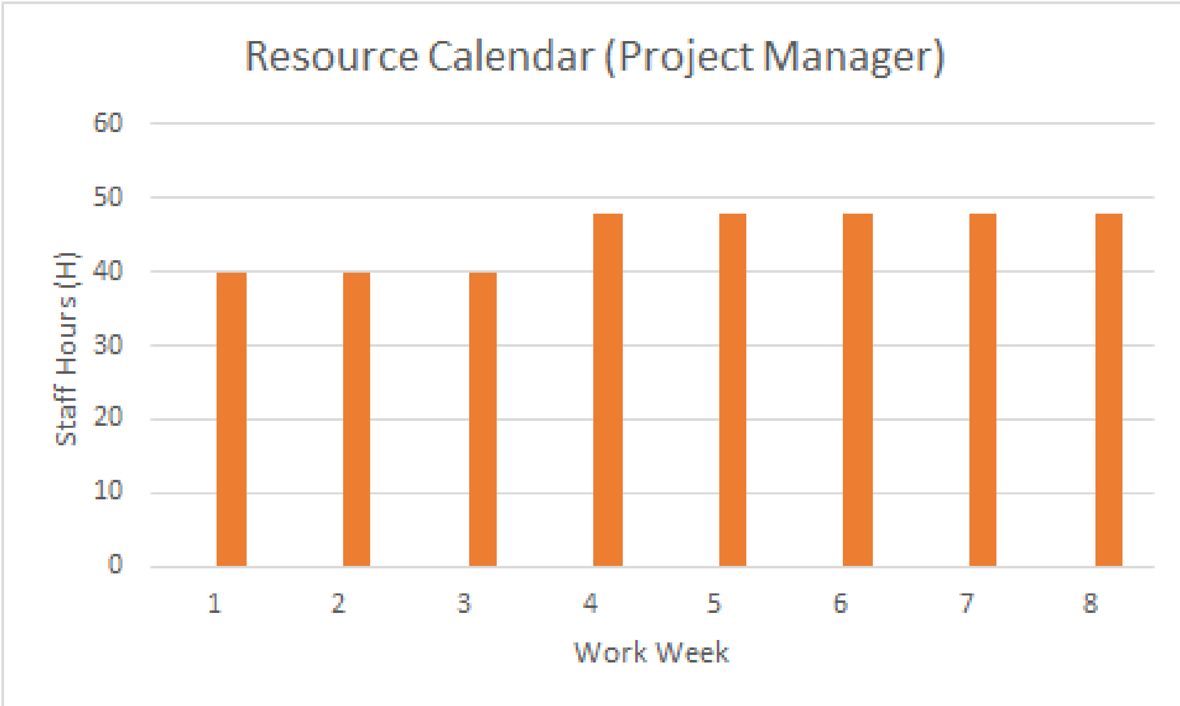


Figure 2: Resource Calendar

Workers are allowed to put in 40 hours a work week before they may get charged overtime. By Canadian law, a worker that exceeds the 40 hour work week must be given permission by their manager to work past the 40 hours. A worker may work up to a maximum of 48 hours a week as outlined by the Ministry of Labor [11]. If a worker exceeds the 48 hours/week law then a fine may be imposed on the company. Other issue that can possibly be faced is the conflict of ideas which includes how to build, how to design, how to program, how much it cost and how many components it need to build this robot work cell.

Therefore, with different ideas a few days of meetings and communicating between workers is required to decide what is the best idea to follow, try to have the simplest idea while completing the task, and at the same time be unique. Another issue that may be unclear is the scope of the project. The workers may create a design that is not aligned with the vision of the customer. Therefore consistent monthly updates will be provided to the customers through email to ensure the design being created fits the customers criteria. By understanding the scope of the robot work cell and the requirements of the customer, a robot work cell can be successfully made. Lastly, one of the main issues may be faced is not finishing building the robot work cell on time, therefore, to solve this issue the solution is to put deadline for each part to avoid this problem.

There are various scenarios might be coming up through this project. One of these scenarios is what if cost of the robot work cell can not be lowered. Although every attempt is made to prepare and present financial information to lower cost, there are times in which unexpected events occur which raises the projects costs. To resolve the issue, many hours of background research will be conducted on the necessary components required and long term relationship with suppliers shall be utilized to ensure the cost is at its lowest. By considering these criterias, the customers needs can be satisfied although the customer wants may be sacrificed to reduce cost. Another "what if" scenario is heavy weight. Weight is one of the most significant factors that affecting the mobility of the robot work cell. The heavy robot requires huge motors and very high capacity batteries, both of that collect even more weights to the machine. Off-the shelf components chosen for the robot are considered lightweight for workers to carry in order for injuries to be minimized. However, certain parts may be considered to heavy for the workers to lift through manual labour.

The parts of the robot work cell that was identified to be heavy are the robots batteries, drive motors and platform. To make the work cell components lighter, there are few steps to follow.

One of this step is to have a smaller size of the battery which in turn reduces the batteries weight. Also, using a lighter material that does not sacrifice the components physical properties can be used to avoid having heavy material. Lastly, using round pieces instead of using square pieces, if possible, would be better for the weight. Therefore, by following these steps, light weight components for the robot work cell can be achieved. All these suggestions are excellent to reduce weight but the drawback is an increase in cost. If the heavy components are absolutely necessary workers can utilize equipment or machinery to transport heavy parts.

The project management plan was formed to achieve the progress of the robot work cell design. Moreover, the design plan was the main planning document for the project, also as it was used to guarantee that all project stages. The project was planned from initiation to installation to usage with the time required to complete each task taken into account. The plan helps workers to stay on schedule, focus on quality and communicate to achieve the design scope. Using the WRIKE Project Management Plan website helped to keep track of the project progress and make sure that everything is on the right path, as it shown in the figure below. Therefore, looking to this project management plan, the time to finish this project of robot work cell is going to take around 50 days, starting from doing research, brainstorming, sketches, reviewing, designing, CAD and end up with writing final report before submission.

	Title	Start	Due	Durati...
	Project Management	15 Oct 2018	3 Dec 2018	51d
1	Group meeting 1	18 Oct 2018	18 Oct 2018	1h
2	Research, ideas, brainstorming and sketches	18 Oct 2018	25 Oct 2018	8d
3	Group meeting 2	25 Oct 2018	25 Oct 2018	1h
4	Review research and sharing idea of the final design	25 Oct 2018	29 Oct 2018	5d
5	Group meeting 3	29 Oct 2018	29 Oct 2018	1h
6	Discuss more in details of the materials that should be u:	29 Oct 2018	1 Nov 2018	4d
7	Group meeting 4	1 Nov 2018	1 Nov 2018	1h
8	Decided for the final design according to features	1 Nov 2018	5 Nov 2018	3d
9	Group meeting 5	5 Nov 2018	5 Nov 2018	1h
10	Safety analysis and start CAD design	5 Nov 2018	8 Nov 2018	4d
11	Group meeting 6	8 Nov 2018	8 Nov 2018	1h
12	Design Final CAD mode	8 Nov 2018	15 Nov 2018	6d
13	Group meeting 7	15 Nov 2018	15 Nov 2018	1h
14	Design of manufacturing	15 Nov 2018	19 Nov 2018	3d
15	Group meeting 8	19 Nov 2018	19 Nov 2018	1h
16	Design Final CAD checked	19 Nov 2018	26 Nov 2018	6d
17	Group meeting 9	26 Nov 2018	26 Nov 2018	1h
18	Report material presented, and review it	26 Nov 2018	29 Nov 2018	4d
19	Group meeting 10	29 Nov 2018	29 Nov 2018	1h
20	Final check for the report before submission	29 Nov 2018	30 Nov 2018	2d
21	Print colour report	30 Nov 2018	2 Dec 2018	3d
22	Submission to Dr. Nokleby	2 Dec 2018	3 Dec 2018	2d

Figure 3: WRIKE Project Management Plan

The date of each part is shown in the project management plan in details. There will be a mechanical engineer, electrical engineer, design engineer, health and safety inspected along with a project manager to ensure the robot work cell design is completed on time and on budget. Each member will have different tasks to undertake for the project. The time required to complete each task is documented for each member to ensure the design is completed on time. The robot work cell cost is considered to be significant, however, it depends on the materials and number of components that are being used. Consequently, it may cost around $35,000 to $75,000 to create the robot work cell to meet the customers goal.

One of the main issues that may be faced is being unable to deliver the robot work cell on time to the customer. This issue will reflect negatively affect those involved in a negative way. Trust between the workers and customer will be diminished and can negatively impact the relationship long term. Furthermore, the reputation of the workers will be negatively impacted if the work is not finished on time. Based on those issues, a project schedule was made to ensure the robot work cell was built on time while being within budget. Each members tasks are outline along with the time needed to complete each activity to ensure progress is going well. Meetings will occur frequently and updates to the customer in terms of the design progress shall be emailed for a sustained relationship.

Brainstorming (Concept Generation)

Concept Generation #1

Introduction

A robotic palletizing system manufactured by Fanuc, Fanuc M410*i*B, possesses the ability to manage palletizing loads of various weight and sizes. The system is equipped with machine vision, which enables robot guidance, useful for inspections or depalletizing [12].

Abstract

The automated palletizing system can manage different sizes and weights of boxes to be loaded. The process involves the utilization of a conveyor belt to pass boxes, followed by the integration of a Fanuc M410*i*B robot to pick and place the loads to produce a layer, and create a layer stacked on top to generate another pallet. The system has the ability to manage up to four different lines consisting of different weights and sizes. Hence, the system has the ability to generate up to four different pallets and stack layers on each [12].

Benefits

This automated palletizing system offers the following:

- Programmed pallet configuration results in accuracy of box placement on pallet
- Minimizes damages of product
- No manpower required

Capabilities (Fanuc M410*i*B)

The Fanuc M410*i*B offers a solution for the following:

- Palletizing
- Depalletizing

- Layer Handling
- Machine load/unload
- Part Transfer

Specifications (Overview)

- End of Arm Tooling: Palletizes 3 cases per minute, 4 different sized cases simultaneously
- End Effector: Vacuum Lift
- Product Variety: up to four sizes
- Price Range: $250,000 - $275,000

Specifications (Fanuc M410*i*B)

- Payload: 160 (kg)
- Reach: 3143 (mm)
- Motion Range: ≤ 540 (degrees)
- Wrist Inertia: 78.5 (kg-m^2)
- Vibration: < 4.9 (m/s^2)
- Mounting Method: Upright

System Specifications

- (1) Robot
- (1) Vacuum Type EOAT
- (1) Pallet Magazine
- (1) Slip Sheet Magazine
- (1) Area Barrier including 2 access doors and 4 full light curtains
- System controls (drives, sensors, panels, wiring, terminal blocks, junction boxes)
- Conveyors
    - (1) 24 foot long infeed case conveyor
    - (1) 7 foot long infeed case conveyor including three Accumulation Zones
    - (4) 5 foot long CDLR Pallet conveyors
    - (2) 7 foot long CDLR Pallet conveyors
    - (2) 12 foot long CDLR Pallet conveyors

Robotic Cell Layout

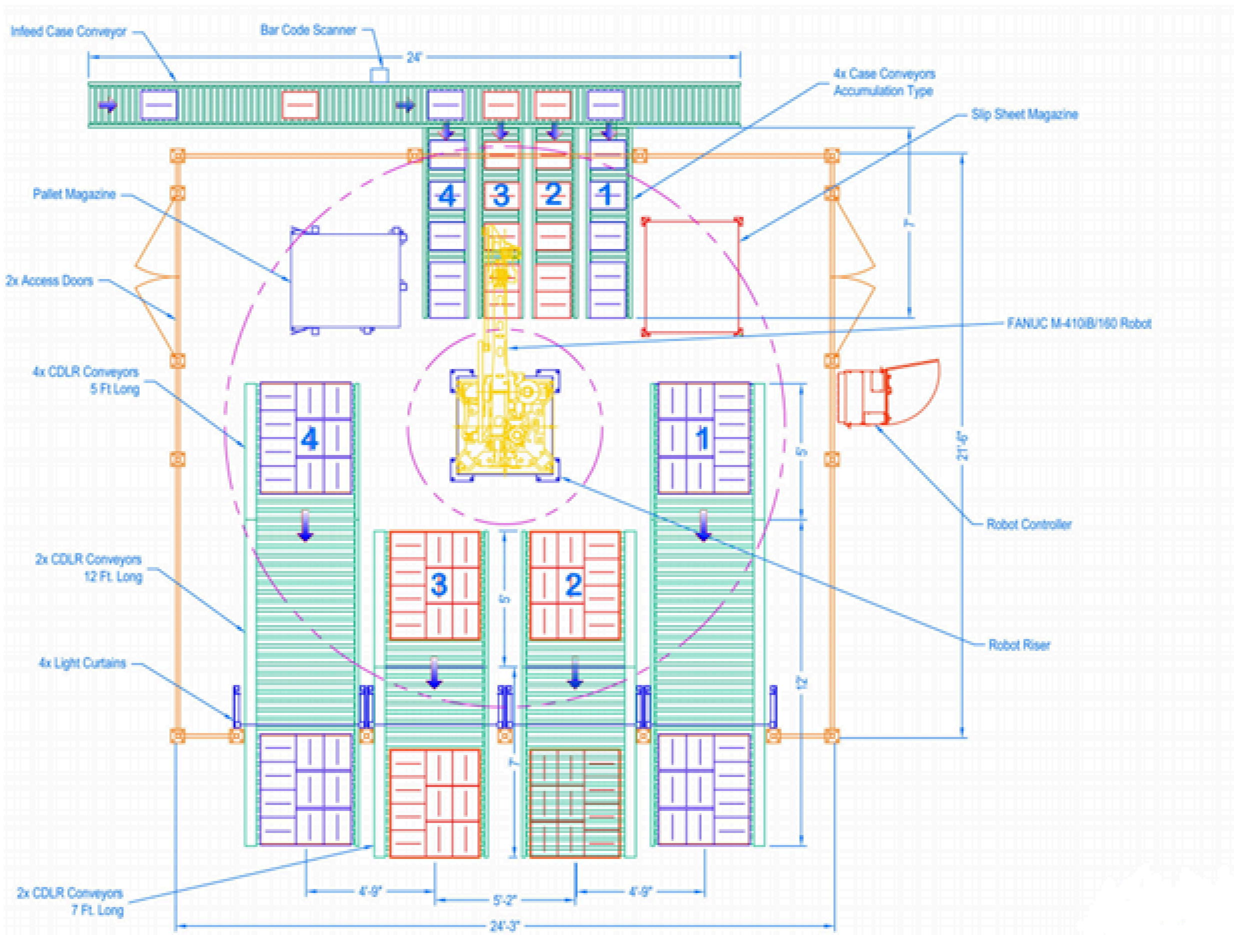


Figure 4: Concept Generation 1 Diagram [12]

Concept Generation 2

Introduction

A robotic palletizing system cell manufactured by Yaskawa Motoman, Arbot-LT™, possesses the ability to manage palletizing loads of various weight and sizes. The system is equipped with machine vision, which enables palletizing and depalletizing in structured or unstructured environments.

Abstract

The automated palletizing system can manage different sizes and weights of boxes to be loaded. The process involves the utilization of an infeed conveyor belt to pass boxes, followed by the integration of a robot, MPL-Series Robot, to pick and place the loads to produce a layer, and create a layer stacked on top to generate another pallet. An expert system is integrated into the design, Pallet Solver® software, which determines the optimal pallet configuration.

Benefits

- Cost effective
- Programmed pallet configuration results in accuracy of box placement on pallet
- Minimizes damages of product
- No manpower required

Capabilities (MPL-Series)

The MPL-Series Robots offer a solution for the following:

- Palletizing
- Depalletizing
- Layer Picking
- Layer Forming
- Machine load/unload
- Part Transfer
- 3D simulation of robot cells, reach modelling, cycle calculations, off-line programming

Specifications (Overview)

- End of Arm Tooling: Palletizes 15 cases per minute, 1 station
- End Effector: Dual zone vacuum plate gripper
- Product Variety: 1
- Price Range: NA

Specifications (MPL500 II)

- Payload: 500 kg
- Reach: 3159 (mm)
- Motion Range: 360 (degrees)

System Specifications (Arbot-LT™)

- MPL-Series Robot
- DX200 Controller
- PalletSolver Software

Features (Arbot-LT™):

- Slipsheet Insertion
- Label-Face Orientation
- Non-Standard Pallets
- Smart Conveyors
- PLC Integrated
- Multi-Zone Gripper
- Partial Layer Forming
- HMI
- Functional Safety Unit (FSU)
- Offline Programming
- Fork-truck loaded pallet stack

Robotic Cell Layout

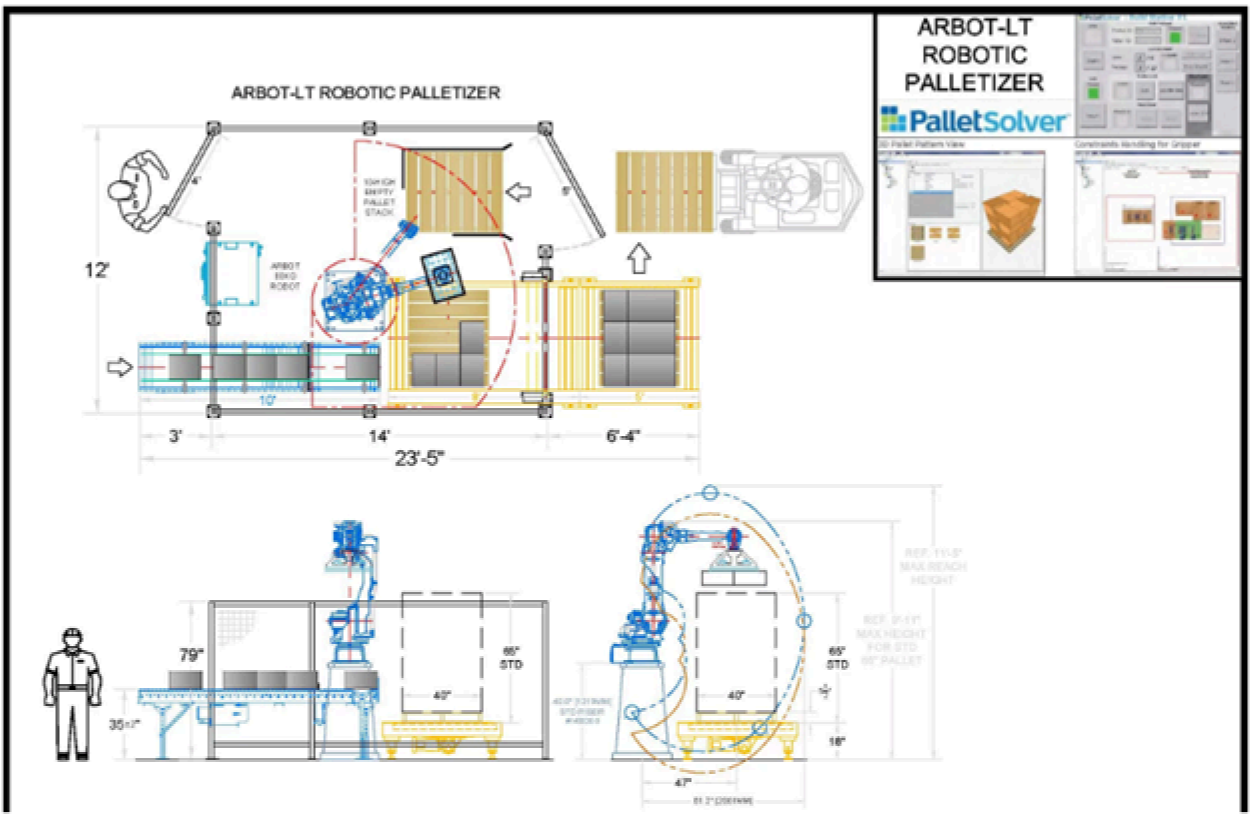
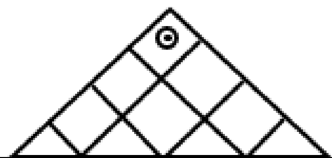


Figure 5: Robotic Work Cell Layout

Concept Selection and Engineering Specifications



Competitive Benchmark: 1 = Very Bad, 2 = Bad, 3 = Neutral, 4 = Good, 5 = Very Good

		WHO	HOW				Competitive Benchmark				
			Maximum Product Dimensions	Maximum Pallet Size	Maximum Payload	Maximum Height					
	WHAT		○	○	↑	↓					
Category	Requirements		in x in x in	in x in x in	kg	in	1	2	3	4	5
Safety Standards	CSA Z434/Z432	40	○	●		●					μ α β
System Functions	Palletizing	20	●	●		●			μ		α β
	Layer Handling	20	●	△	△	●					μ α β
	Part Transfer	20			●				μ α		β
Technical Difficulty			2	1	4	3					
Importance Sum			560	720	480	200					
Importance Normalized (%)			28.6	36.7	24.5	10.2					
Relative Importance			2	1	3	4					
Target Values			24″ x 12″ x 8″	48″ x 48″ x 6″	10	48″					
Objective Measures	Arbot-LT™		32″ x 16″ x 12″	96″ x 48″ x 12″	500	80″					
	Fanuc Palletizing System		32″ x 16″ x 12″	96″ x 48″ x 12″	160	80″					
	ABB Work cell		24″x 16″ x 12″	48″ x 48″ x 12″	110	70″					

Legend # 1: Customer Ratings
μ = ABB Work cell
α = Arbot-LT™
β = Fanuc Palletizing System

Legend # 3: How-How Relationship
⊙ = High Positive Correlation
+ = Positive Correlation
− = Negative Correlation
⊖ = High negative Correlation
Blank = No correlation

Legend # 2: How-What Relationship
● = Strong Relationship (9)
○ = Medium Relationship (3)
△ = Weak Relationship (1)
Blank = No Relationship (0)

Legend # 4: Meeting Target Values
↑ = Maximize
↓ = Minimize
○ = Meet Target Value

Using a House of Quality, the competitors robot work cell compared to the robot work cell considered for palletization were considered. The requirements of the robot work cell was to follow the safety standards for CSA Z434 and Z432. As well, the system functions were emphasized which included the ability to palletize the cardboard boxes, ability to stack the boxes in alternating layers and transport the boxes from one side to the other.

Engineering characteristics involved was the maximum dimension possible for the robot work cell, the maximum pallet size that was able to fit within the robot work cell, maximum payload that can be handled by the industrial robot and the maximum height of the hazard. Areas of improvements considered was the need to minimize the robot work cell area and the height of the hazard. Reducing the robot work cell area allows more space for other applications involved. The robot work cell should be minimized by the right amount to still allow the robot to function appropriately. The height of the hazard zone should be reduced to eliminate cost for building safety fences. Increasing the maximum pallet size allowed in the robot work cell area and the maximum payload of the robot would reduce the possibility of failure and allow more work to be done quickly.

A competitive benchmark was performed for each product. For all the robot work cells, the safety standards as outline in CSA Z434 and Z432 were followed. The Arbot and Fanuc work cells were able to palletize more products than the ABB work cell area. All robots were able to layer the cardboard boxes in alternating positions. For transferring part, the Fanuc and ABB work cell were moderate in handling payloads compared to the Arbot work cell.

The most important category to consider was the pallet size. The requirement from the customer was to palletize boxes onto a pallet that was 48” x 48” x 6”. The ABB work cell is able to perfectly palletize the cardboard boxes as required onto a pallet. The Arbot and Fanuc work cell are easily capable of palletizing the boxes specified. The second most important feature is the space taken up by the robot work cell. The robot work cell area should allow packages of certain dimension to enter through the robot work cell to be palletized. The ABB, Fanuc and Arbot work cell allows the cardboard boxes enter the area for palletization. The next important category was the maximum payload that can be carried by the robot. The minimum weight that the robot must carry is 10 kg. All the robots being used in the robot work cell is easily able to transport the cardboard boxes as required. Lastly, the maximum height of the robot work cell area should be reduced to save on cost for safeguarding over the safety fences. All robot exceed the target value with the ABB work cell being the lowest in terms of hazard height.

Based on the the criterias considered, the best work cell selected for the purpose of palletizing boxes is the ABB work cell. The ABB work cell was chosen because of its ability to meet the minimum requirements to palletize 10 kg cardboard boxes of 24” x 12” x 8”. The other robots were more than capable of palletizing the boxes, however, due to the features and ability of the work cell this increases the cost significantly. Since one of the customer requirements was to save on cost while being able to successfully complete its objective, the ABB work cell was the best candidate to fulfill the requirements. The decision to use the ABB work cell was further supported by using a Decision Matrix.

	Robot work cell allows the robot to complete its job successfully (5)	Components used are economical (4)	Robot work cell considers safety designs to protect workers (5)	Robot work cell does not consume much space(3)	Total Sum
Concept #1 (ABB Work Cell)	High - Adequate space is given for the robot to successfully complete its task 3 x 5 = 15	High - components used are inexpensive 3 x 4 = 12	High - fences, light sensors and emergency stop buttons have been considered 3 x 5 = 15	Medium - The robot work cell requires fences that take up a large amount of space 2 x 3 = 6	48
Concept #2 (Fanuc Palletizing System)	High - Adequate space is given for the robot to successfully complete its task 3 x 5 = 15	Low - components used are inexpensive but many components are required 1 x 4 = 4	Medium - fences, light sensors, and emergency stop buttons have been considered. However, many components means maintenance will be difficult 2 x 5 = 5	Medium - The robot work cell requires fences that take up a large amount of space 2 x 3 = 6	35
Concept #3 (Arbot-LT)	High - Adequate space is given for the robot to complete its task	High - components used are inexpensive	Medium - fences and emergency stop buttons have been considered. Other safety devices should be considered	Medium - The robot work cell requires fences that take up a large amount of space	43

	3 x 5 = 15	3 x 4 =12	2 x 5 = 10	2 x 3 = 6	

Figure 6: Decision Matrix

Engineering and Design Analysis

A clamp gripper was chosen to successfully palletize the cardboard boxes. The gripper is required to lift a 10 kg cardboard box from the conveyor belt and palletize the boxes. The main components used for the gripper is steel, iron, aluminum and rubber. Steel, iron, and aluminum as used as the main components of the gripper because of their light weight, low cost, high strength, and heat resistant properties. The rubber is placed inside of the gripper and is used to firmly grasp the cardboard boxes.

In order for the gripper to firmly transport the cardboard boxes to the pallets, the force required for the gripper to prevent the cardboard box from slipping needs to be calculated. The force of the cardboard box due to gravity is 98.1 N acting downwards towards the ground. Therefore the end effector would need to apply an equivalent force of 98.1 N upwards to counteract the force acting downwards. Using the frictional force formula, as shown below, the normal force applied by the gripper can be found:

Frictional force = μ* Normal Force

The static frictional coefficient between the rubber grippers and the cardboard box is 0.5 - 0.8 for a dry environment [13]. An average value of 0.65 will be chosen as the static frictional coefficient. Since each gripper is holding either sides of the cardboard box the frictional force is divided by 2. Solving for normal force the value was found to be 75.46 N. Therefore, each gripper would need to apply 75.46 N on each side to ensure the load remains static.

The situation presented is ideal for end effectors that have new rubber grippers installed and iw working in a dry environment. If the operating condition was damp or the rubber grippers have been worn out the end effector may not be able to sustain the load. An improvements that can be made on the end effector design is by adding a support at the bottom. The support would assist the gripper by lifting the cardboard box for palletization. The force applied from the gripper could be reduced and the issue of worn out grippers or wet environment can be eliminated. However, another issue that arises from changing the design is the potential for tipping. If the cardboard box is not positioned correctly or if the component being used is not strong enough, the load would bend the support and tip over.

Assuming that the area at which the support will lift the cardboard box is 24” x 12” (0.6096 m x 0.3048 m) the stress from the cardboard box would be 527.97 N. The stress is distributed throughout the supports area. The next issue that arises is the minimum thickness required to ensure the box is lifted properly. Using the stress equation, shown below, the support height (h) can be calculated:

$$\sigma = \frac{Mc}{I}$$

$$I = \frac{1}{12}(b)(h)^3$$

The bending moment due to the load is 14.95 Nm, assuming that the load applied is a point mass located at the center of the cardboard box and the support is 12 inches (0.3048 m) in length. Using the moment of inertia for a rectangle and isolating for the height, the minimum allowable height for the support would be 0.70 mm.

Functional Decomposition

The requirement of the project is to design a robot work cell capable of allowing a robot to palletize cardboard boxes, weighing 10 kg each, while also adhering to safety standards CSA Z434 and CSA Z432. The robot work cell would consist of the following components:

Robot

The robot that would be used for this work cell is IRB 460. It is the fastest palletizing robot in the world and is appropriate for the application of the project [20]. The robot is designed to allow the pallets to be placed twenty percent closer when compared to the competitors, this by itself increases the productivity by up to three percent. The robot is able to shorten cycle times which increases productivity. Moreover, by the use of QuickMove™ and TrueMove™, the robot provides smooth movements and high path accuracy [20]. The physical dimensions of the robot base is 1007 x 720 mm ,and the weight of the robot is 925 kg [20]. Moreover, the supply voltage is 200-600 V (50-60 Hz) ,and the power consumption is ISO cube 3.67 kW [20]. The reach of the robot is 2.4m with handling capacity of 110 kg. Safety is taken into consideration as the robot has double circuits with supervisions, 3 position enable device and emergency stop and safety, to ensure safety [20].

Drag Chain Conveyor (I)

The following conveyor would be used to supply the items to the work cell. The length and the width of the following conveyor are 24 ft x 24 ft [19]. The frame of the following conveyor is powder painted formed steel angle with a wall and chain support tube. The bearings are sealed and pre-lubricated [19]. Moreover, the capacity it can hold up to is 5800 lbs, maximum at 30 FPM. The specifications of the motor include, 1.5 HP and 60 HZ gearmotor, that is located underneath the 5ft. long module [19].

Drag Chain Conveyor (II)

The following conveyor is used for the boxes once they have entered the work cell. The length and the width of the following conveyor are 48 ft x 48 ft. the frame of the following conveyor is powder painted formed steel angle with a wall and chain support tube[18]. The bearings are sealed and, pre-lubricated. The chain is a single pitch conveyor chain with UHMW polyethylene chain guide [18]. Moreover, the capacity that it can hold up to is 5800 lbs, maximum at 30 FMP. the specification of the motor include, 1.5 HP and 60 HZ gearmotor, that is located underneath the 5 ft. long module [18].

Fences

The fences are used to provide a safe environment.The fencing used for the robot workcell are ST30 panel. The dimensions of the fence are 1250 mm x 1500 mm [21]. Inorder, to create a stable, strong and resistant panel, the vertical wires are welded to the crossing tubes, and the horizontal welded into the frame [21]. A safety distance of 120 mm from the hazard is achieved due to the narrow mesh size, therefore ensuring safety.

Light Sensor

The light sensor that would be used for the robot work cell is GL-R60H. The light source is Infrared LED. For the detection mode, it turns on when no interruptions are present in the detection zone [17]. The weight of the transmitter is 1670g and the receiver is 1680g. Moreover, aluminum is used for the main unit case and, Nylon for the upper case/lower case [17]. The maximum current consumption for the transmitter is 72(mA) and, 82(mA) for the receiver[17].

Functional Decomposition Diagram

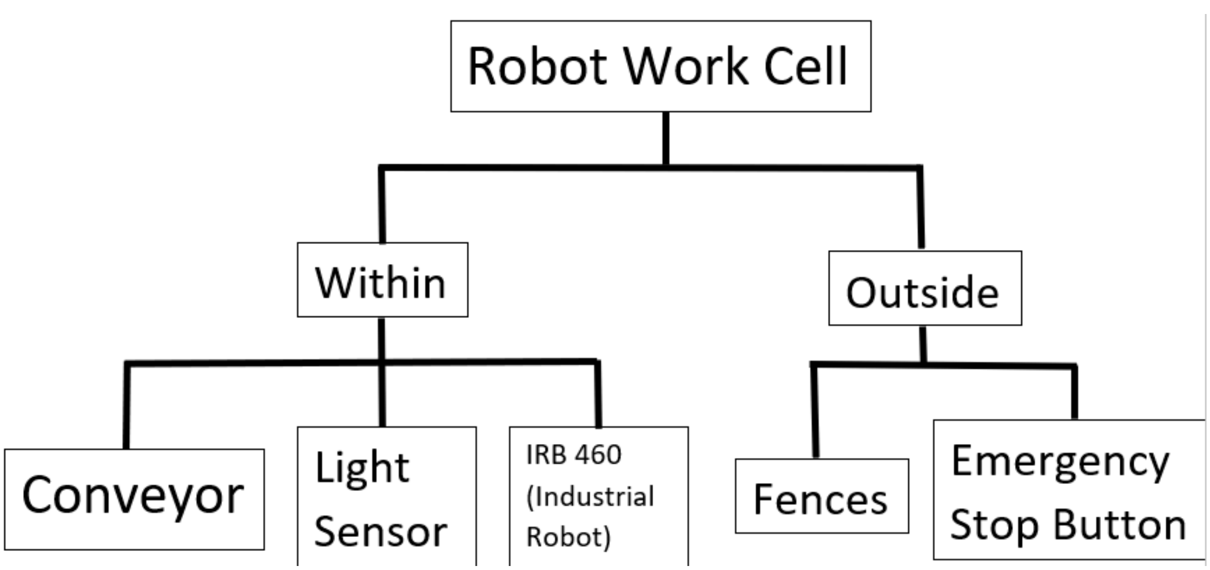


Figure 7: Functional Decomposition Diagram

A functional decomposition diagram was created to identify the necessary components for the robot work cell. A conveyor belt, light sensor and the IRB 460 robot are positioned inside the robot work cell area. Outside of the robot work cell area is the safety fences and the emergency stop button which is placed in a convenient location in case the operation is needed to be stopped immediately. In addition, a concept combination table was created to showcase the relationship between the energy source that is being used, the components that are involved and the function of the components.

Energy Source	Component	Function
Electrical Energy	Conveyor Belt	Palletize Boxes
	Robot	

Figure 8: Concept Combination Table

Bill of Materials (B.O.M)

A Bill of Materials has been created to showcase the products that will be used to create the robot work cell. The Bill of Materials includes the components being used, a description of each component, size, material, cost, and the manufacturer that to purchase the product.

Part No.	Quantity	Name	Description	Size	Material	Cost	Source
1	1	IRB 460	Industrial Robot used for palletizing boxes	Base: 1007 x 720 mm	Stainless Steel, Aluminum, Iron	$250	ABB Product Page
2	2	Safety Fences	Fences (without opening) to prevent objects from going to the hazard zone	3603 mm (L) x 1786 mm (H)	Stainless Steel	$250	ABB Product Page

3	1	Safety Fences (Input Opening)	Fence (with opening for input) to prevent objects from going into the hazard zone	3603 mm (L) x 1786 mm (H) with a 635 mm (L) x 228.6 mm (H) opening	Stainless Steel	$250	ABB Product Page
4	1	Safety Fences (Output Opening)	Fence (with opening for output) to prevent objects from going into the hazard zone	3603 mm (L) x 1786 mm (H) with a 1244.6 mm (L) x 1397 mm (H) opening	Stainless Steel	$250	ABB Product Page
5	1	GL-R60H	Light curtain to detect the cardboard boxes	1120 mm (L) x 1225 mm (H) with a 1180 mm detection height	Aluminum	$285	Keyence
6	1	Drag Chain Conveyor	Conveyor belt to transport the cardboard boxes out of the hazard zone	609.6 mm (L) x 609.6 mm (W)	Stainless Steel, Aluminum	$18,280	Bastian Solutions
7	1	Drag Chain Conveyor	Conveyor belt to transport the cardboard boxes into the hazard zone	1219.2 mm (L) x 1219.2 mm (W)	Stainless Steel, Aluminum	$10,102	Bastian Solutions
8	1	Clamp Gripper	End effector used to transport cardboard boxes	Maximum Product Size: 650 mm (L) x 500 mm (W) x 330	Stainless Steel, Aluminum, Iron	$17,000	ABB Product Page

				mm (H) Minimum Product Size: 200 mm (L) x 200 mm (W) x 150 mm (H)			

Figure 9: Bill of Materials

Design for Manufacturing

Conveyor belts are wide belts attached in a loop to at least two turning rotors driven by motors. The loop is a real conveyor belt and is commonly made of at least two layers of elastic, one layer to give shape and structure to the belt and the other to transport an object securely. The conveyor loop is commonly attached to two wheels, called rotors, which are spun by motors. The conveyor belt has enough grinding among it and the rotor that adheres to the rotor. Picking the correct belting material is a necessity for conveyor frameworks on the grounds that the wrong material could jeopardize profitability or worker wellbeing. Conveyor frameworks, particularly those in assembling offices, travel through a wide range of situations. For instance, sequential construction system conveyors may go through a broiler, underwater parts washer or some kind of auxiliary task like an artistic creation. In this way, they should be resistant, strong and ready to deal with these cruel conditions on a consistent and customary premise.

Belts that transport consumable goods, crude materials and unpackaged merchandise are made of either hardened steel or a heat resistant, non-debasing plastic pitch. They should be FDA or USDA endorsed and simple to clean and disinfect. Materials like some hard plastics or metal do not have the adaptability expected to pass on, which requires the belt to twist, as they are on a constant loop around two arrangements of rollers.

In these circumstances, little parts are interlocked together or woven with the end goal to twist and bend. Nonetheless, these will in general have openings or breaks and are not smooth or watertight. They are not made for conveying little or sporadically formed questions and in addition items in sacks, which could list or become lost despite a general sense of vigilance.

A Light sensor is utilized to identify light and make a voltage distinction. The two primary light sensors by and large utilized in robots are Photoresistor and Photovoltaic cells. Different sorts of light sensors like Phototubes, Phototransistors, CCD's and so on are once in a while utilized.

A photoresistor is a resistor that opposes fluctuation of light intensity and makes adjustments to the light; more light prompts means less obstruction and less light prompts means more obstruction. These economical sensors can be effectively executed in most light ward robots. Photovoltaic cells convert solar radiation into electrical vitality. This is particularly useful on the off chance that a robot that relies on solar energy is used. Photovoltaic cell is considered as a vitality source, an astute usage joined with transistors and capacitors can change over to a sensor.

To understand the RIA standard, the robot should not have the capability to affect the safety fences. The robot has a working space and outside of that is the confined space that is dictated by figuring the halting separation for the particular robot model and EOAT. The confined space is irrefutably the maximum separation the robot ought to ever "float" when the security monitoring limits are surpassed.

Outside of the limited space, there ought to be a 20" zone to take into consideration space for an administrator while instructing. The space is given to eliminate tight tolerances. There may be occasions in which the client would want less space between the hazard zone and the fences. A small distance between the hazard zone and the fences can be provided but would need to follow the CSA standards. The CSA standards entails that the distance between the fence and the hazard zone will be the reachable workspace of the arm in addition to a clearance distance between the two. The edge shielding will not be introduced nearer to the danger than the confined space except if - the border protecting is designed to be the restricting gadget, in which case it should completely restrain the robot movement - or the hazard appraisal decides other defending is appropriate.

Clause 5.12.2 in Part 1 requires mechanical stops be equipped for halting the robot at evaluated stack, maximum speed, and at the maximum and least augmentation. On the off chance that the edge monitor is the restricting gadget, it must meet these prerequisites. Where the border defending is the limiting gadget, extra measures might be required to ensure people inside the protected space. There is a 304.8 mm x 203.2 mm hole between the conveyor framework and the 1800mm tall metal fence. There are two entryways with optical sensors that will close off the tasks on the off chance that it crossed while in activity except if generally given an overwrite order. The Occupational Safety and Health Administration has issued directions for conveyor security, as OSHA 1926.555. The temperature of the storage space isn't to surpass 40 degrees Celsius. The arranging territory isn't to surpass 40 degrees Celsius. There are 8 fans required to be in the arranging zone to counteract dust develop.

The robot arm ought to be light-weight with the goal that dormancy while moving will be limited and the conceivable effect if there should arise an occurrence of impact isn't harmful. Contradictory to this, the joint connections ought to be as solid as conceivable to meet the exactness needs of the developments. On the off chance that the robot arm contacts people, that ought to be recognized by sensors. The likelihood of having a configuration in the robot arm such that human injuries ought to be averted by equipment design or possibly by programming limitations. The robot's physical design ought to have no sharp edges in each joint. Every joint corner are to be designed with smooth spans. All power and flag links and cylinders must be secured inside the arm with the goal that nobody can be adhered to the link. When making the robot gathering tasks, the settling components ought to likewise be inside the spreads for a similar reason.

These impossible to miss and contradictory design limitations, together with low equipment cost targets, have brought about administration robot designs looking very comparable. The connection configurations are associated through round cylinders, all control PCBs and wiring secured inside the joints, motors secured and nothing reaching out from the robot body. The spreads are made of plastics and strengthened strands, to coordinate the light-weight objective.

Numerous 3D filtering technologies can enhance the idea and design periods of a robotic work cell. Outside of those applications, utilizing 3D software can analyze and provide greater adaptability in a work cell. For instance, by utilizing 3D filtering, tight tolerances can be discovered and, whenever required, give a worker an idea on areas to allow more spacing to be provided. Another precedent is to utilize 3D scanners to review the part before it is taken care by the robot. Lastly, by checking parts, any issues that has been found can be analyzed and examined from the robot program. This makes 3D scanners useful since it requires less contribution from an administrator, enabling them to concentrate on different assignments.

On the off chance that measurements are overlooked in which quality issues may occur, the electrical connectors would be the least impacted component long-term. Using electrical connectors to connect the wires from a long distance to links and pneumatic cylinders would be a strategy to ensure components are energized. This resolves the bolstering issue of adaptable links and pneumatic cylinders inside the rounded connections of the robot arm. The links must also have additional length to coordinate the necessities of the moving robot arm. That additional length should likewise be taken care of in a foreordained shape, and that is the reason the links are contorted. This issue with link distension is the most convoluted and basic assemblability issue in administration robotics. Likewise, at the joints, the links must be situated in a settled position. Round cylinders have a huge burden. The round shape does not position the joints consequently and precisely to the joints on the rotational hub. This needs additional consideration and care. Either there must be sharp position imprints or some fabricated position situates in the parts. The most troublesome method is an adjustment estimation to have the connections adjusted precisely.

A coating that will be used to protect the robot work cell is a liquid glass shower which delivers a water-resistant covering just around 100 nanometers (15-30 atoms) thick. On this nanoscale, the glass is very adaptable and breathable. The covering is ecologically harmless and non-lethal, and simple to clean utilizing just water or a straightforward wipe with a damp cloth. It repulses bacteria, water, and soil, and resists heat, UV light, and even acids.

Design for Safety

In any type of industry, safety is regarded as the most important criteria an organization must fulfill. The definition of safety varies among different industries. For a company that uses robots to complete various tasks, preventing unnecessary injury and damage between a worker and robot is critical to a safe working environment. Following safety standards and procedures is important, especially in a manufacturing company that uses robots and heavy machinery. The group investigated safety designs of a robot work cell that would be compatible for the robot arm. The safety criterias were considered throughout the production and installation of the robot arm and work cell. CSA Z434, CSA Z432, and ISO 13857 were a few among the many safety guidelines followed.

To ensure all workers are safe while on the job companies are expected to follow safety protocols and procedures outlined by the Canadian government and globally recognized safety guidelines. As described before, different industries have different types of safety procedures they must follow. For example, when constructing a building industrial companies must use materials that are non-toxic and are able to withstand certain stresses. Even though each industry has different protocols to follow there are many similarities that can be found. The goal of a safety guideline is to keep the public and the workers safe from harm. Safety attributes will be explored throughout the robot work cell.

Safety measures were considered based on the customer needs and wants. The customer requirements have been listed below:

Customer Needs

- Sturdy robot work cell that allows a robot to complete the objective successfully
- Robot work cell that is economical
- Robot work cell that has safety designs implemented to protect workers
- Robot work cell that does not consume much space
- Robot that is economical
- Robot that is able to palletize 10 kg boxes in the shortest time possible

Customer Wants

- Robot that has many degrees of freedom
- Robot work cell that allows a robot to change its end effector to perform other tasks if required
- A mobile robot work cell that is mobile and lightweight
- Robot work cell that is easy to assemble, disassemble and repair if needed
- Robot work cell is made of parts that are easily obtainable and quick to deliver

The area of the robot work cell was considered to ensure adequate space was given for the robot to complete its task. This was based on the reachable workspace of the robot in addition to a minimum (safety) distance to install the fences. The robot work cell also has safety fences that are 1800 mm high to prevent parts from leaving the hazard zone and personnels from entering the danger zone. Light curtains have been installed to detect people or objects that enter the work cell area unexpectedly. 2 emergency stop buttons have been installed in accessible areas for situations which requires the robot to stop operating immediately.

With the area defined for the robot work cell, the height of each guard should be considered. Height of the guards is dependent on the risk category selected, minimum distance calculated, and the height of the hazard.

Risk Categorization

Risks are classified in 2 categories Low and High.

3 sub-categories, as listed below, are considered to categorize the risk type for the robot work cell:

1) Injury Severity
2) Exposure
3) Avoidance

Ratings for each sub-category can range between values of 1 to 3 depending on the criteria chosen. A value of 1 is considered unlikely to occur or causes minor injuries while a score of 3 is given for severe situation or a high possibility of an undesirable action to occur. It is assumed that the robot will be able to perform its duties without the need of human interference or monitoring.

A worst case scenario was selected for each criteria to account for possible outcomes. Considering Injury Severity, the robots reachable workspace extends to 2403 mm. If a person was to come in contact with the robot, the worst possible injury that the individual could sustain is a broken bone. This would lead to the individual receiving immediate medical attention and a visit to the hospital causing a loss of time. Extra measures such as light curtains and sensors on the robot have been installed to reduce the potential of injury. As well, the robot is assumed to be performing its duties without the interference or monitoring of an external source. Fatality will not occur in the workcell since the individual would be wearing personal protective equipment. Safety shoes, helmet, protective clothing, and safety glasses will significantly reduce the severity of the injury. Therefore the rating given to the robot work cell for injury severity would be S2 (Moderate).

With the assumption that the robot will be able to perform its duties without the need of human interference or monitoring an exposure rating of E1 (Low) will be given. The only time an individual will be exposed to the robot is for maintenance and repair. Maintenance and repair would occur monthly to keep the workcell at its optimal capacity.

Lastly, the robot will be provided a sufficient amount of space to operate and bright colors will be used to indicate potential hazards . The reduced speed of the robot will not exceed 250 mm/s, a requirement within CSA Z434. A workcell fence and sensors will be installed around the workcell area to assist the worker in avoiding the hazard zone. As a result the rating for avoidance factor will be A1 (Likely)

With the ratings for each category defined, a decision matrix was used to determine the Risk Reduction Priority. For a rating of S2, E1, and A1 the risk priority assigned for the robot work cell will be PR3 (Low).

Table DVA.1 – Hazard severity/exposure/avoidance categories

Factor	Rating	Criteria (Examples) - choose most restrictive *The decision process starts at the top*
Injury Severity	Serious S3	Normally non-reversible: – fatality – limb amputation – long term disability – chronic illness – permanent health change If any of the above are applicable, the rating is SERIOUS
	Moderate S2	Normally reversible: – broken bones – severe laceration – short hospitalization – short term disability – loss time (multi-day) – finger tip amputation (not thumb) If any of the above are applicable, the rating is MODERATE
	Minor S1	First aid: – bruising – small cuts – no loss time (multi-day) – does not require attention by a medical doctor If any of the above are applicable, the rating is MINOR
Exposure	High E2	– Typically more than once per hour – Frequent or multiple short duration Durations/situations which could lead to task creep and does not include teach, see NOTE 1 If any of the above are applicable, the rating is HIGH
	Low E1	– Typically less than or once per day or shift – Occasional short durations If either of the above are applicable, the rating is LOW
Avoidance	Not likely A2	– insufficient clearance to move out of the way – inadequate warning/reaction time – hazard is moving faster than reduced speed (250 mm/s) – may not perceive the hazard exists If any of the above are applicable, the rating is NOT LIKELY
	Likely A1	– sufficient clearance to move out of the way – adequate warning/reaction time – hazard is moving at or less than reduced speed (250 mm/s) If any of the above are applicable, the rating is LIKELY

Figure 10: Hazard severity/exposure/avoidance categories [14] [15]

Table DVA.2 – Risk reduction decision matrix prior to safeguarding and safety integration

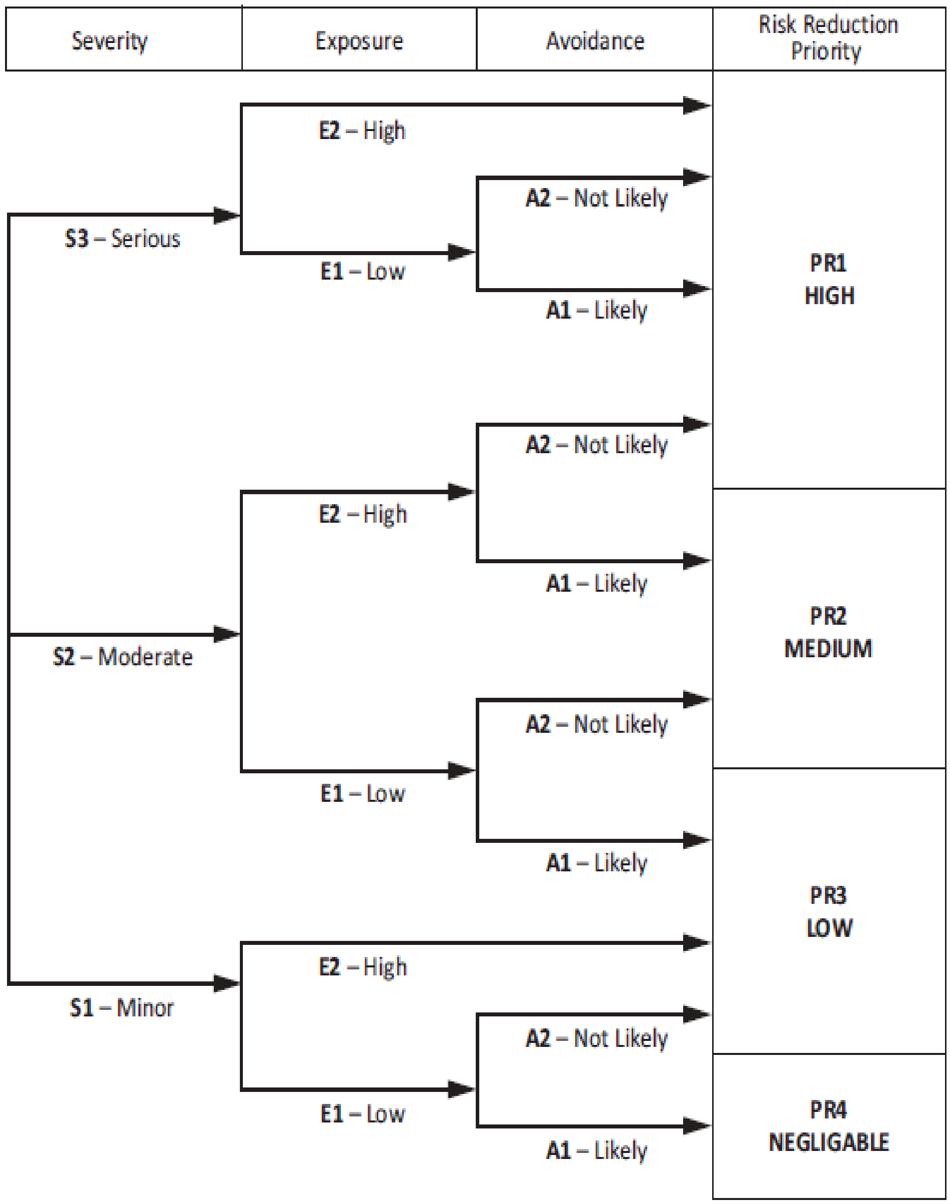


Figure 11: Risk Reduction Decision Matrix [14] [15]

Table DVA.3 – Minimum safeguarding measures

<table>
<tr><th>Risk reduction priority</th><th colspan="3">Safeguarding measures</th></tr>
<tr><td>PR1
HIGH</td><td rowspan="4">Inherently safe design measures Hazard elimination or hazard substitution</td><td rowspan="2">Risk reduction by safeguarding</td><td rowspan="2">Fixed guard preventing access; engineering controls preventing access to the hazard, or stopping the hazard, e.g., interlocked guards, light curtains, safety mats, or other sensitive protective equipment implemented to meet a functional safety performance</td></tr>
<tr><td>PR2
MEDIUM</td></tr>
<tr><td>PR3
LOW</td><td rowspan="2">Complementary protective measures</td><td>Non-interlocked guards, clearance, procedures and equipment</td></tr>
<tr><td>PR4
NEGLIGIBLE</td><td>Awareness means</td></tr>
</table>

Figure 12: Minimum Safeguarding Measures [14] [15]

For PR3 the use of non-interlocked guards, clearance, written procedures and personal safety equipment is required. In addition, complementary protective measures must be installed and sufficient distance is required to reduce or eliminate the hazard. These requirements have been addressed within the report to keep both the worker and the work cell area safe from harm.

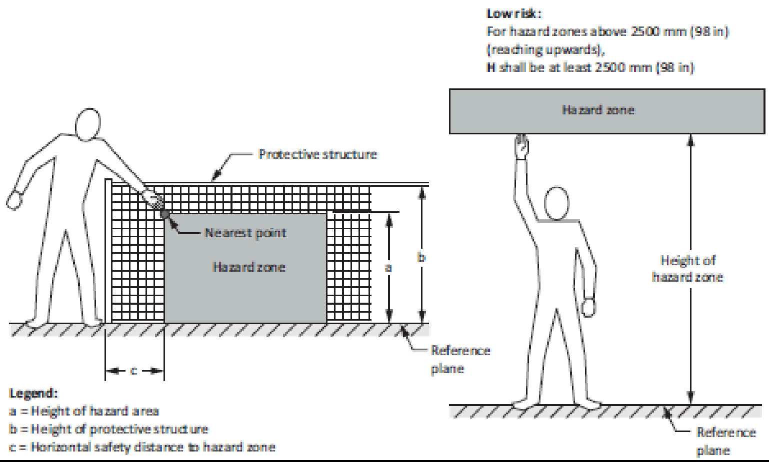
The first safety feature to be installed for the robot work cell area is the safety fences. The safety fence is a barrier that separates the worker from accidently walking into the hazard zone. The safety fence also prevents materials from exiting the work cell area. 2 types of guards that can be installed around the work cell area are Removable Guards or Fixed Guards. Each guard type has specific requirements within CSA Z434 and Z432 that needs to be followed to ensure both workers and the work cell area are safe. Summarized information regarding requirements for each guard type has been attached to the Appendix for reference.

The height of the guard is dependent on the minimum (safety) distance from the hazard zone. The minimum distance is dependent on the type of risk identified and the height of the hazard zone. The height of the hazard is chosen to be the highest reachable workspace the robot can reach. This height was considered because a fence that is lower than the reachable workspace height can pose a significant risk to worker safety. As a result, the height of the safety fences was chosen to be 1786 mm high.

As stated before, the risk priority assigned to the robot work cell was PR3 (Low). Since the risk is considered low a low risk table from ISO 13857 can be used to determine the height of the safety fence.

Δ Table DVB.2: Low risk reaching OVER a guard or protective structures
Horizontal minimum (safety) distance for LOW RISK when reaching over a guard or protective structures

Where the injury severity is low (e.g., reduction priority PR3 or PR4 per Annex DVA), the Low Risk table may be used.
When reaching upwards towards the hazard zone, the height (H) to the hazard shall be at least 2500 mm (98 in).



Height of Hazard zone *c* *a*	Height of Protective Structure *b* — *Dimensions in millimetres*								
	1,000 (39)	1,200 (48)	1,400 (55)	1,600 (63)	1,800 (72)	2,000 (80)	2,200 (87)	2,400 (94)	2,500 (98)
	Horizontal minimum (safety) distance to hazard zone *c* LOW RISK								
And higher 2,500 (98 in)	0	0	0	0	0	0	0	0	0
2,400 (94)	100 (4)	100 (4)	100 (4)	100 (4)	100 (4)	100 (4)	100 (4)	100 (4)	0
2,200 (87)	600 (24)	600 (24)	500 (20)	500 (20)	400 (16)	350 (14)	250 (10)	0	0
2,000 (79)	1,100 (43)	900 (36)	700 (28)	600 (24)	500 (20)	350 (14)	0	0	0
1,800 (72)	1,100 (43)	1,000 (39)	900 (36)	900 (36)	600 (24)	0	0	0	0
1,600 (63)	1,300 (51)	1,000 (39)	900 (36)	900 (36)	500 (20)	0	0	0	0
1,400 (55)	1,300 (51)	1,000 (39)	900 (36)	800 (31)	100 (4)	0	0	0	0
1,200 (48)	1,400 (55)	1,000 (39)	900 (36)	500 (20)	0	0	0	0	0
1,000 (39)	1,400 (55)	1,400 (55)	900 (36)	300 (12)	0	0	0	0	0
800 (31)	1,300 (51)	900 (36)	600 (24)	0	0	0	0	0	0
600 (24)	1,200 (48)	500 (20)	0	0	0	0	0	0	0
400 (16)	1,200 (48)	300 (12)	0	0	0	0	0	0	0
200 (9)	1,100 (43)	200 (9)	0	0	0	0	0	0	0
0	1,100 (43)	200 (9)	0	0	0	0	0	0	0

NOTE 1 – This table has been adapted from ISO 13857.

NOTE 2 – Do not interpolate numbers. Use the figures that will result in a more conservative outcome. For example, if the height of the hazard is 1300 mm (51 in), then use 1400 mm (55 in). If the protective structure height is 1900 mm (75 in), use 1800 mm (72 in) to determine what the safe distance should be.

Figure 13: Low risk reaching over a guard [14] [15]

Using the table, for a hazard height of 1800 mm and safety distance of 600 mm from the hazard zone the height of the protective structure would be 1800mm high.

With the risk requirement satisfied for reaching over a guard consideration must be taken into account for potential hazard under a guard. Spacing under a guard must be less than than 150 mm (6 inches) otherwise a worker can slide underneath a guard [CSA Z434]. To prevent such a situation from happening Table DVB. 4 from CSA Z432 and Z434 was used to find the maximum spacing allowed. With a safety distance of 600 mm the largest space underneath a guard is 17.26 mm. The values were calculated using interpolation and has been attached to the Appendix for reference.

Table DVB.4: Reaching UNDER a guard or protective structures
Horizontal minimum (safety) distance when reaching under a guard or protective structures

Opening Under a Guard (fixed or interlocked) ***e* mm (in)**	**Safety Distance mm (in)**
Smallest Dimension	
$e \leq 4$ (0.2)	≥ 2 (0.1)
4 (0.2) $\leq e \leq 12$ (0.5)	≥ 10 (0.4)
12 (0.5) $\leq e \leq 20$ (0.8)	≥ 120 (5)
20 (0.8) $\leq e \leq 80$ (3)	≥ 850 (33)
80 (3) $\leq e \leq 150$ (6)	≥ 1100 (43)
Over 150 (6)	Not Allowed unless other safeguarding is provided to prevent access or detect access

Figure 14: Reaching under a guard [14] [15]

The next safety measure to consider is human appendages through a guard opening. Using ISO 13857 for reaching through a guard, the largest dimension allowed for a guard opening can be found. Guard openings can be in the form of many shapes including slots, square, circles or irregular shapes. The group decided that a guard opening for a slot shape was the best approach to undertake. Using square or round openings would prevent thin objects from getting through the fences but is more expensive because of the extra materials needed. Irregular shapes are not recommended because of the complex shape to manufacture and the significantly high cost to do so.

Using a safety distance of 600 mm and a slotted opening the hand would be the only human appendage that would fit through the slot opening. The largest opening allowed for a slotted fence was calculated to be 16.83 mm wide. The values were calculated using interpolation and has been attached to the Appendix for reference.

Conveyor belts will be used to transport cardboard boxes into the workcell area for palletization. To prevent human appendages from reaching inside the work cell area a light sensor will be installed. The light sensor monitors different objects that enter the workcell area. If an object is larger than the dimensions allowed by the light sensor, the robot would undergo an emergency stop. The light sensors will be installed at a minimum (safe) distance from the robot work cell area. Minimum (safe) distance is the length from the light sensor to the hazard zone. The minimum (safe) distance can be written and calculated from either formulas defined below:

CSA Z434

$$D_s = [K * (T_s + T_r)] + D_{pf}$$

$$D_{pf} = 3.4 * (Os - 6.875)$$

D_s - Minimum Distance (mm)
K - Speed of the robot arm (mm/s)
Ts - Slowest stopping time (ms)
Tr - Response time (ms)
Dpf - Depth Penetration Factor (mm)
Os - Object Sensitivity

ISO 13855

S = (K x T) + C

C = 8 x [Os - 14mm]

S - Minimum Distance (mm)
K - Speed of the robot arm (mm/s)
T - Slowest stopping time and Response time (s)
C - Depth Penetration Factor (mm)
Os - Object Sensitivity

For the report, minimum distance will be calculated using the formula provided by CSA Z434. The speed at which the cardboard boxes enters the workcell area will be the minimum allowable speed into the light sensor. As defined in CSA Z434 the velocity will be 1600 mm/s. The response time is the time required for the robot to detect, recognize, decide and react to an event . Emergency stop time is the time required by the light sensor to stop all operations. The light sensor that will be taken into consideration is a GL-R60H. The response time for the light sensor and emergency stop time for the IRB 460 is 0.01s and 0.45s respectively. Lastly, to calculate the Depth Penetration Factor the objective sensitivity must be known. Object sensitivity measures the dimension of an object to determine if it is acceptable for use. Since the box will be entering the robot work cell at 8 inches or 203.2 mm, the value will be chosen as the Object Sensitivity value. Using the Depth of Penetration formula, the result was found to be 667.505 mm. Plugging in all values into the minimum distance formula indicates that the safety distance between the light curtain and the worker is approximately 1400 mm. The calculation for all results has been attached within the Appendix.

The robot work cell has been designed to be ergonomic and prevent unnecessary injuries to an individual. The robot work cell will be designed to be easily assembled, disassembled and repaired if required. Components for the work cell have been designed to be light weight and mobile if the work cell is required to be relocated. The parts use for the robot work cell are easily obtainable off the shelf components that can be found on the manufacturers website and complies with the safety standards listed in CSA Z434 and CSA 432.

Before the robot can be installed, the Risk Priority Number (RPN) must be calculated to assess all possible risks involved. RPN is measured on a scale from 1 (best) to 1000 (worst). The formula for RPN is given by the following

RPN = S x O x D

S = Severity
O = Occurrence
D = Detection

Severity is the intensity of an injury should failure occur. Occurrence represents the possibility of failure to occur during the robots lifetime operation. Lastly, detection represents the effectiveness to identify all potential failures that may occur. The values measured for S, O, and D is from 1 (best) to 10 (worst).

The RPN given to the IRB 460 was 45. The results were calculated based on the following decisions considered.

If the robot arm were to fail, safety measures and precautions have been installed to reduce and eliminate the severity of the failure. The robots emergency stop time is 0.45 s and will be activated by the sensors on the robot arm if an object is identified or if the emergency stop has been activated. A minimum safety distance has been calculated for the work cell area to minimize the risk of injury. Safety fences and sensors have been installed around the hazard area to further reduce the possibility of injury. Based on the specified information, a severity value given for the robot arm will be 3.

Design considerations have been proposed to reduce the possibility of failure during the robots lifetime operation. Maintenance which includes cleaning the work cell area will be performed frequently. As a result, the occurrence value proposed for the robot arm will be 5. Improvements such as having a feedback control system would reduce the occurence number.
The group has sat down and considered possible failures that may occur during operation. Some of these failures include an individual that may accidentally walk into the hazard zone. Another issue considered was the minimum safety distance between the light curtain and the worker. With several different possible issues identified the Detection value was given a 3. Improvements to detect unforeseen problems includes hiring a subject matter expert with experience working on industrial robots to determine additional problems that have been overlooked.

When the robot work cell has been installed, safety measures must be taken into account during energization and operation. Through research, 6 Severity Level Designs were identified during the robots operation. The 6 Severity Level Designs describes safety measures required for an individual that is close to or within the danger zone to prevent unnecessary injuries from occurring. In addition to the Severity Level Designs, CSA Z434 and CSA Z432 were considered to ensure all regulations were followed. The following Severity Level Designs have been identified below:

1) In close proximity to the cell area
2) Approaching the work cell area
3) Entering the work cell area
4) Approaching the hazard zone
5) Entering the potential danger zone
6) Entering the immediate danger zone

Severity Level 1

At a Severity Level 1 the use of large, bright, legible warning signs located in a viewable area is sufficient enough to indicate a potential hazard. A potential design choice that could be made is using a bright yellow sign that is large enough to be readable at far distances and could be placed near a doorway to alert workers of the danger [16].

Severity Level 2

When a person approaches the work cell area a barrier should be installed. The guard should prevent an individual from accidently entering the danger zone. Yellow lights that warn people of potential hazards should be installed nearby [16].

Severity Level 3

For Severity Level 3 the worker should be aware of their surrounding at all times. Pressure Sensitive Protective Equipment (PSPE) such as pressure mats will reduce the possibility of an injury. When the PSPE has been activated, lights should flash to warn workers of danger and the robots speed should decrease [16].

Severity Level 4

Workers that approach the hazard zone should be made aware that they are about to exceed the minimum (safe) distance. Active Opto-electronic Protective Devices (AOPD), such as a light curtains, should be installed at the work cell area. The AOPD provides feedback to the system and prepares the robot to slow down if a worker has been detected. In addition, lights should be red to indicate an increased severity of danger and a buzzer should sound to alert all personnels within the vicinity [16].

Severity Level 5

The danger zone is defined as the reachable workspace area of a robot. The use of pressure mats and light curtains are extremely important in the area. Both devices monitor the area to ensure a worker has not entered the potential danger zone. If an individual has reached the potential danger zone flashing red lights and a continuously sounding buzzer should be activated. The lights and buzzer should grab the workers attention and let the individual know to exit the potential danger zone immediately. While all guards have been activated the robot should come to a complete stop if a personnel has been detected. Once the worker has left the area the robot should be able to resume operation [16].

Severity Level 6

Severity Level 6 is the highest severity level achievable. If an individual has entered the immediate danger zone all necessary measures should be taken to prevent the robot from contact the individual. Sensors should be installed on the robot arm to detect objects that are close to the robot. Red flashing lights and a continuously sounding buzzer should immediately capture the workers attention and let them know of imminent danger. The robot should be able to stop immediately if the emergency stop button has been pressed as stated in CSA Z434. All power to the robot and other equipment within the imminent danger zone should be disconnected. A restart will be required to restore power to the system [16].

Conclusion

All safety considerations from CSA Z434, CSA Z432, and various ISO documents were taken into account when designing the robot work cell. Customer requirements and luxuries were identified to ensure the basic customer needs were fulfilled while going above and beyond. Different concepts were considered and a new concept was designed, which combined the advantages of researched concepts while satisfying customer needs and reducing cost. The selection was performed based on using multiple engineering tools such as a House of Quality and Design Matrix. A project management plan was considered to ensure the design of a robot work cell was on time and on budget. Necessary components were researched and a functional decomposition of each component was included to understand the robot work cell layout. A manufacturing analysis was performed on each component and tolerances were considered when choosing the components. Engineering analysis was performed to recognize possible failures that may occur during palletization. Lastly, a design for the robot work cell safety was prioritized to ensure the robot work cell area and workers were safe from danger. Use of light sensors, fences, emergency stop buttons and other safety devices were considered for the design.

Appendix

Minimum (Safety) Distance

$D_s = [K * (T_s + T_r)] + D_{pf}$

$D_{pf} = 3.4 * (Os - 6.875)$

$D_{pf} = 3.4 * (203.2 - 6.875)$

$D_{pf} = 667.505\, mm$

$D_s = [1600\, mm/s * (0.01\, s + 0.45\, s)] + 667.505\, mm$

$D_s = 1403.505\, mm$

Distance under the Guard

$\frac{600\, mm - 120\, mm}{e - 12\, mm} = \frac{850\, mm - 120\, mm}{20\, mm - 12\, mm}$

e = 17.26 mm

Spacing

$\frac{600\, mm - 120\, mm}{e - 12\, mm} = \frac{915\, mm - 120\, mm}{20\, mm - 12\, mm}$

e = 16.83 mm

Clamp Gripper

$Weight = (9.81\, m/s^2 * 10\, kg)$

Frictional force = μ* Normal Force

$(9.81\, m/s^2 * 10\, kg) = 0.65 \;\; * 2 * Normal\, Force$

$Normal\, Force \;=\; 75.46\, N$

Support

$\sigma = \frac{F}{A}$

$\sigma = \frac{(98.1N)}{(0.3048\, m)(0.6096m)}$

$\sigma = 527.97\, N$

$\sigma = \frac{Mc}{I}$

$527.97N = \frac{(98.1N)(0.3048\, m)}{\frac{1}{12}(0.6096m)(h^3)}$

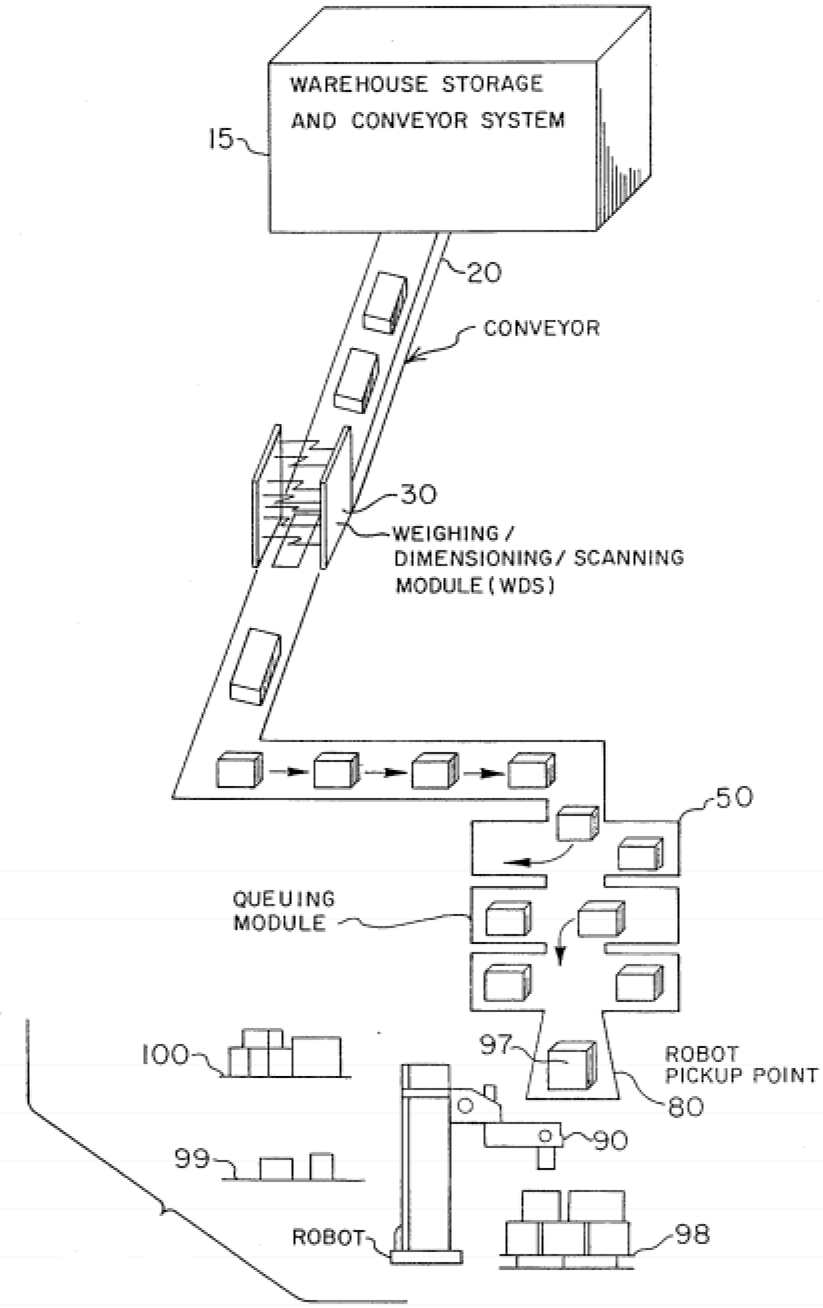
$h^3 = \frac{(98.1\, N)(0.3048\, m{*}2)(0.6096\, m)}{\frac{1}{12}(0.6096m)(527.97N)}$

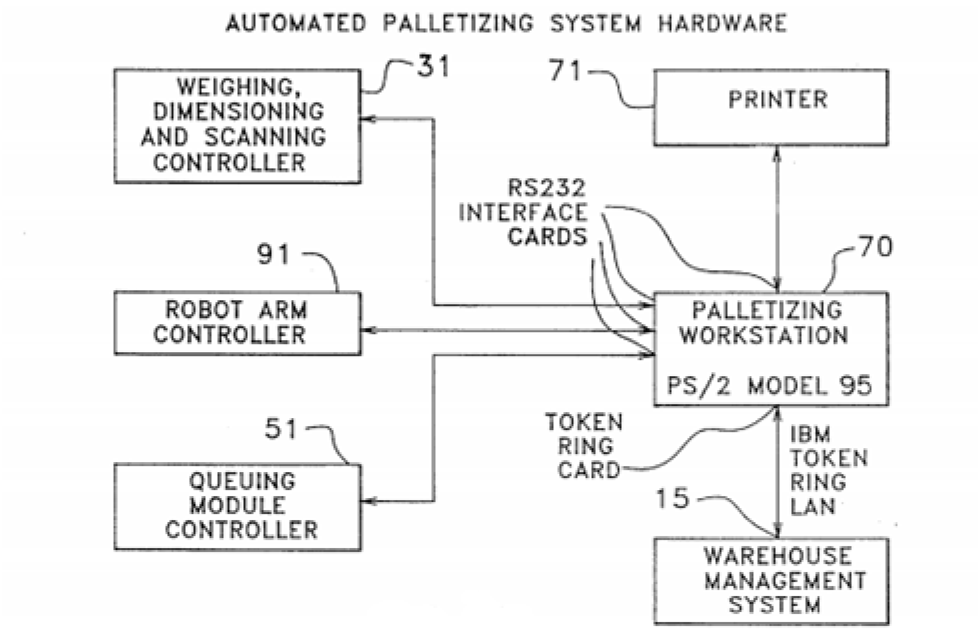
$h = 0.70\, mm$

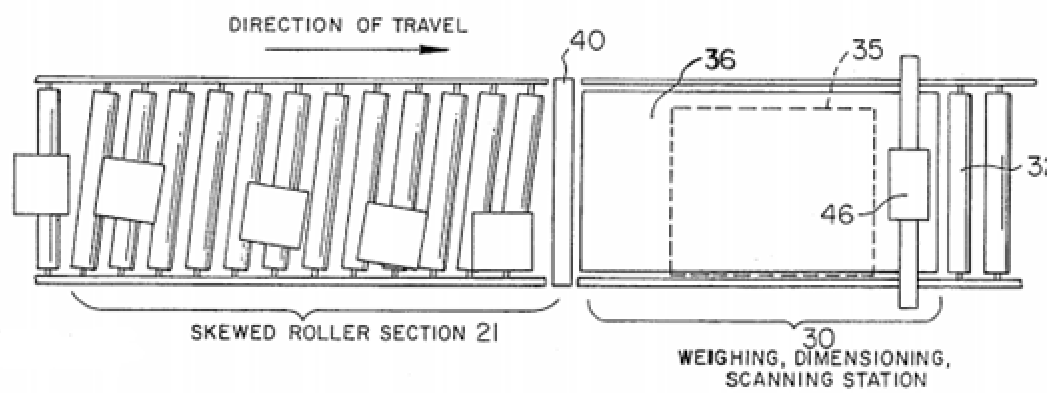
Diagrams for Background Research #1

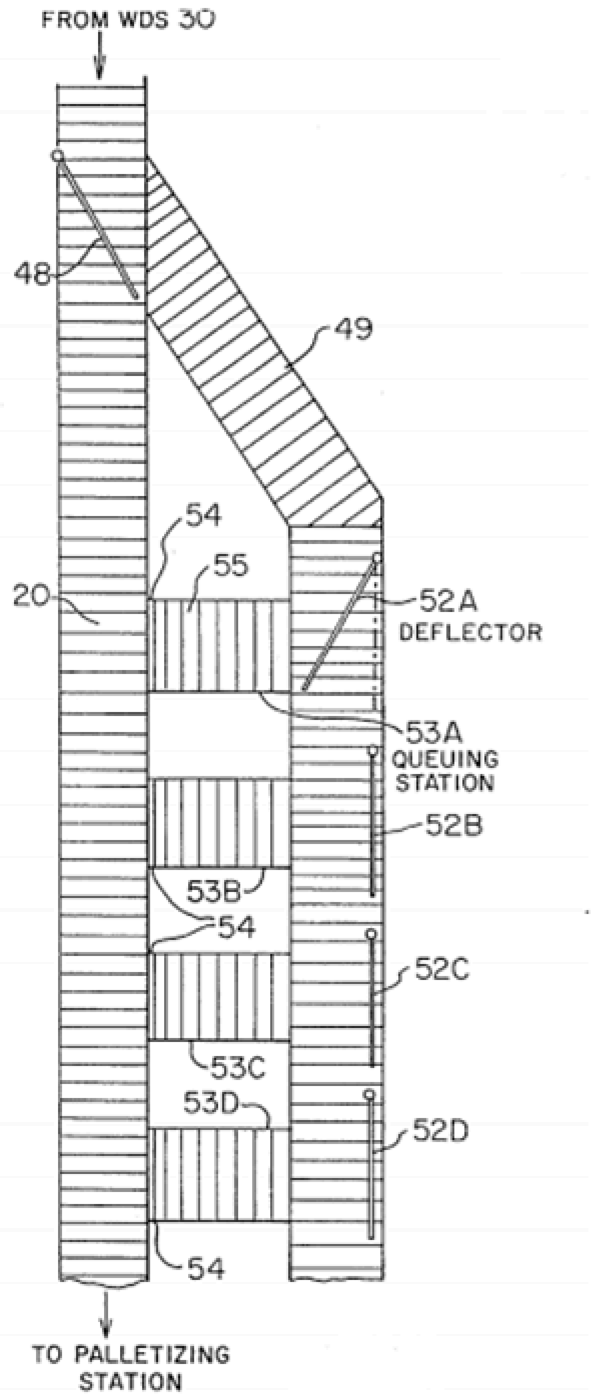
Figure A.1: System diagram of invention, exemplifying the mechanical interactions between the components of the system.
Figure A.2: System diagram of invention, exemplifying the electrical interactions between the elements of the system.
Figure A.3: Top view diagram of invention, exemplifying the dimensioning, scanning and weighing station.
Figure A.4: Top view diagram of invention, exemplifying the queuing module.
Figure A.5: Top view diagram of invention, exemplifying the robot arm loading station.
Figure A.6: Flow diagram of invention, exemplifying the logic regarding the pallet configuration.

Figure A.7: Flow diagram of invention, exemplifying the logic regarding the construction of a new pallet.
Figure A.8: Flow diagram of invention, exemplifying the logic regarding the construction of a new layer.
Figure A.9: Flow diagram of invention, exemplifying the logic regarding the acquisition of a box's dimensions.
Figure A.10: Flow diagram of invention, exemplifying the logic regarding heavy boxes.
Figure A.11: Flow diagram of invention, exemplifying the logic regarding light boxes.
Figure A.12: Flow diagram of invention, exemplifying the logic regarding the box's placement in the queue.
Figure A.13: Flow diagram of invention, exemplifying the logic regarding the placement of a box.

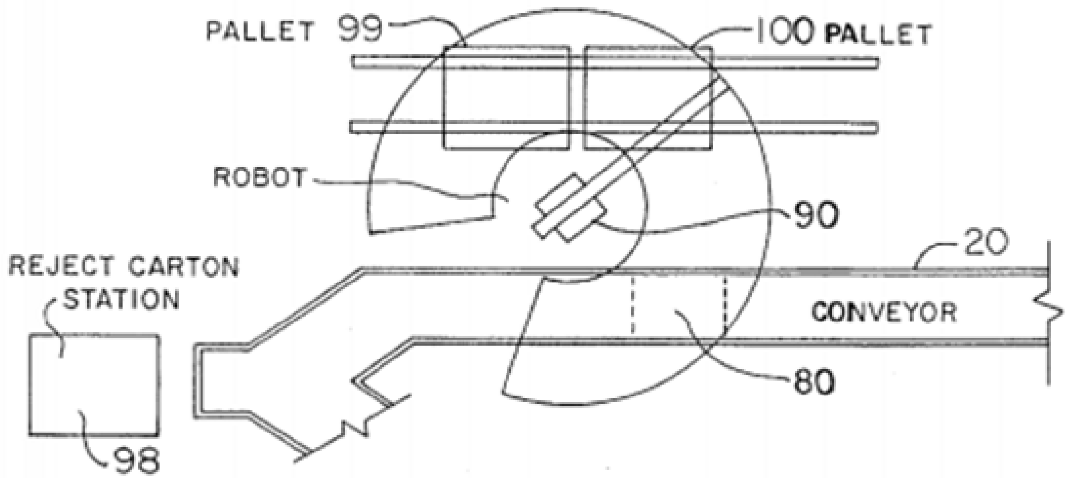

WAREHOUSE STORAGE
AND CONVEYOR SYSTEM
15
20
CONVEYOR
30
WEIGHING /
DIMENSIONING / SCANNING
MODULE (WDS)
50
QUEUING
MODULE
97
ROBOT
PICKUP POINT
80
100
90
99
ROBOT
98

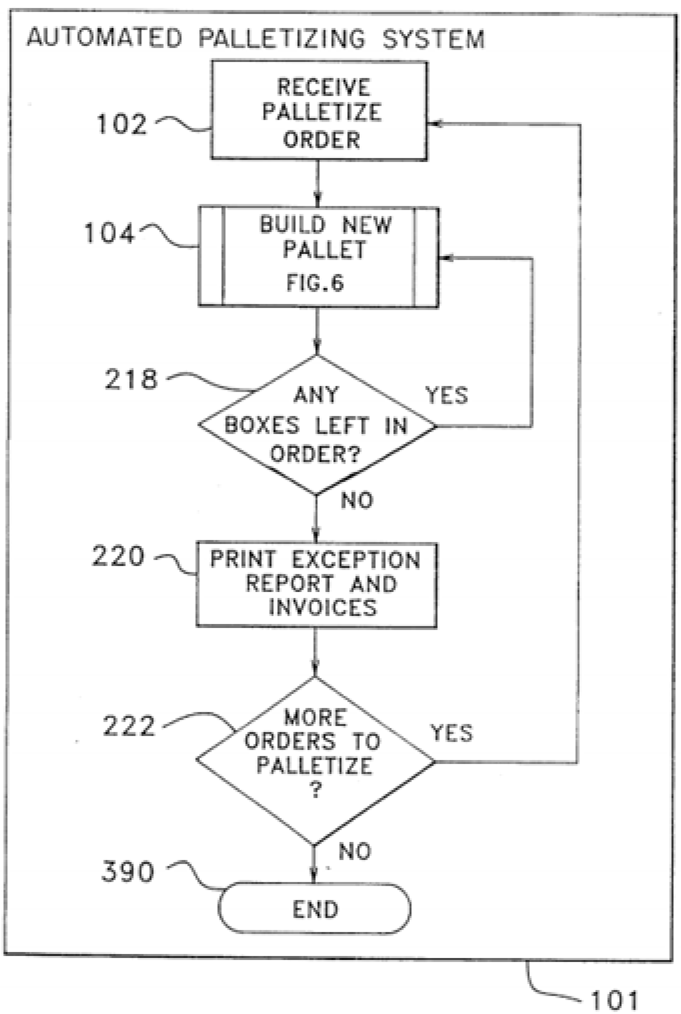

AUTOMATED PALLETIZING SYSTEM HARDWARE
WEIGHING, DIMENSIONING AND SCANNING CONTROLLER
31
71
PRINTER
RS232 INTERFACE CARDS
91
70
ROBOT ARM CONTROLLER
PALLETIZING WORKSTATION
PS/2 MODEL 95
51
TOKEN RING CARD
IBM TOKEN RING LAN
QUEUING MODULE CONTROLLER
15
WAREHOUSE MANAGEMENT SYSTEM

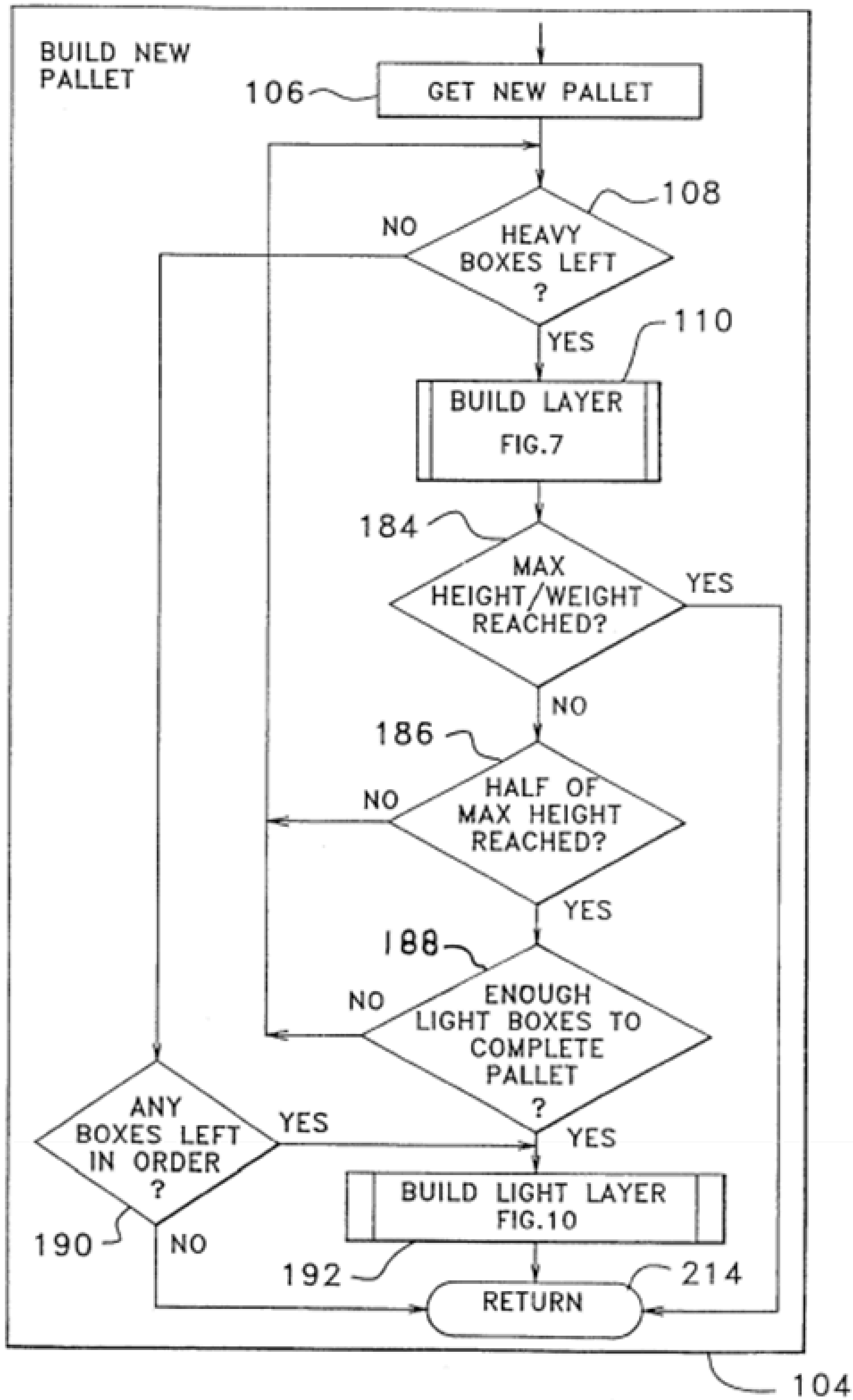

DIRECTION OF TRAVEL
40
36
35
32
46
SKEWED ROLLER SECTION 21
30
WEIGHING, DIMENSIONING, SCANNING STATION

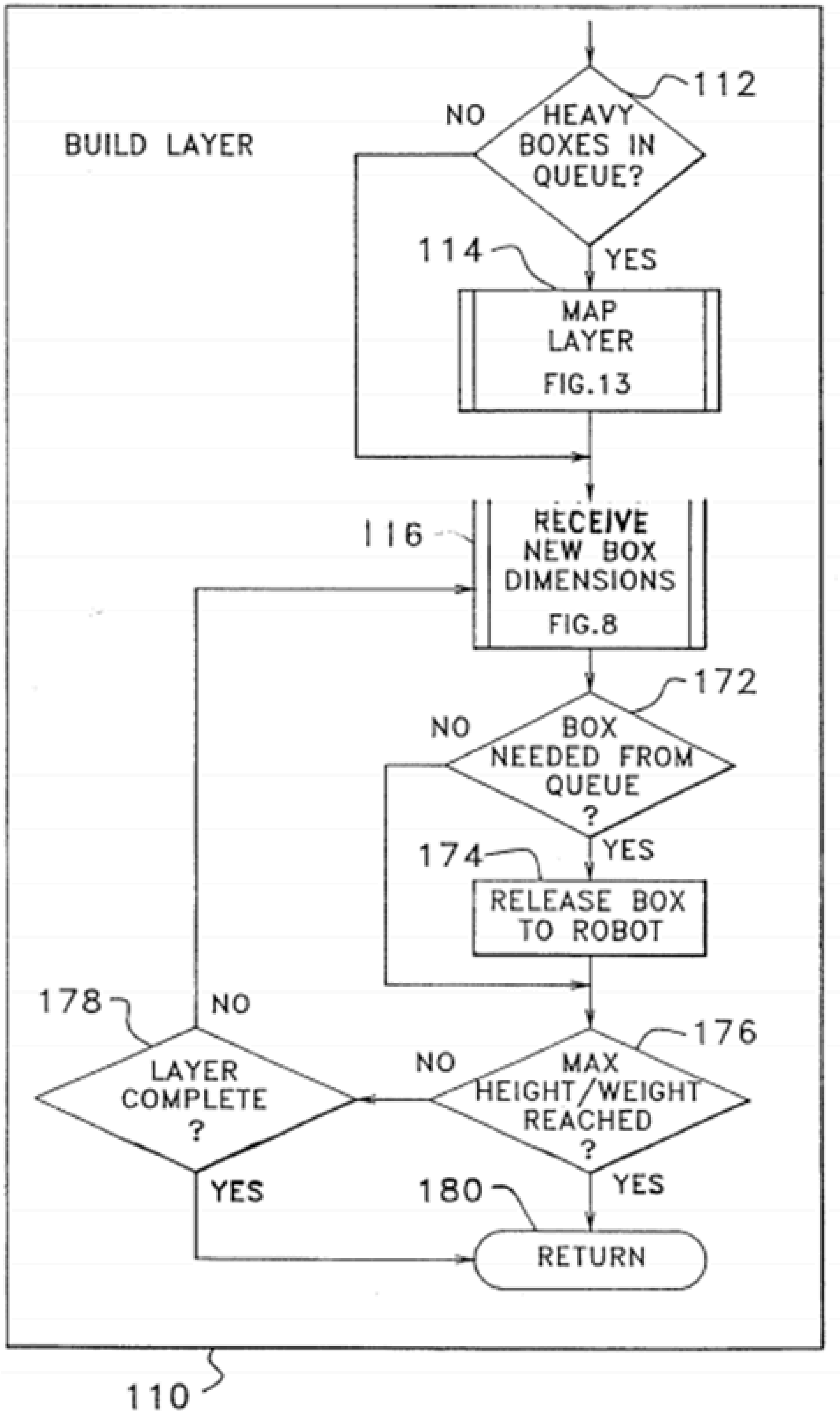


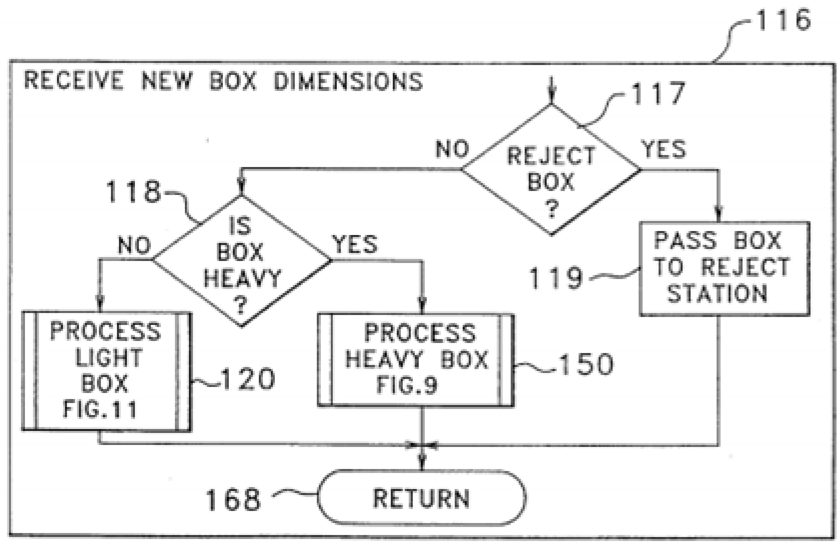
FROM WDS 30
48
49
54
55
20
52A
DEFLECTOR
53A
QUEUING
STATION
52B
53B
54
52C
53C
53D
52D
54
TO PALLETIZING
STATION

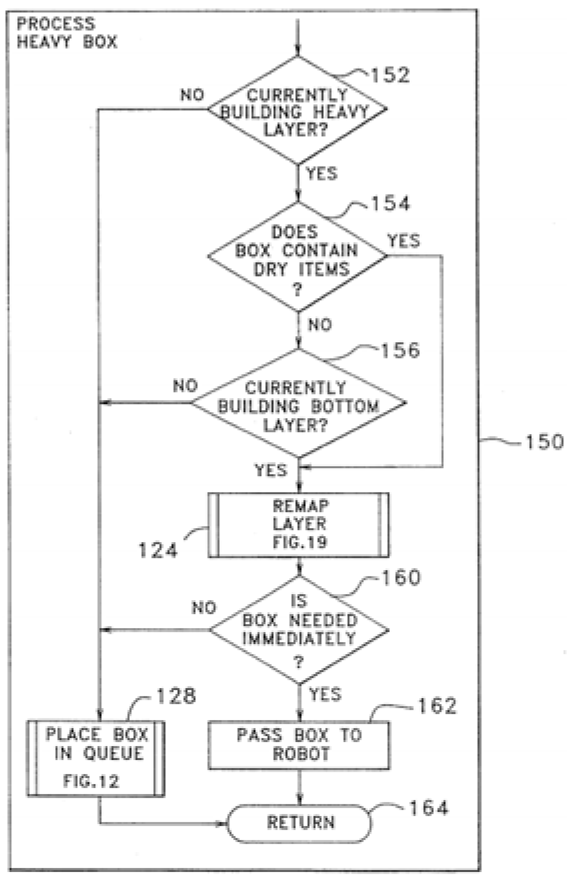

PALLET 99
100 PALLET
ROBOT
90
20
REJECT CARTON STATION
CONVEYOR
80
98

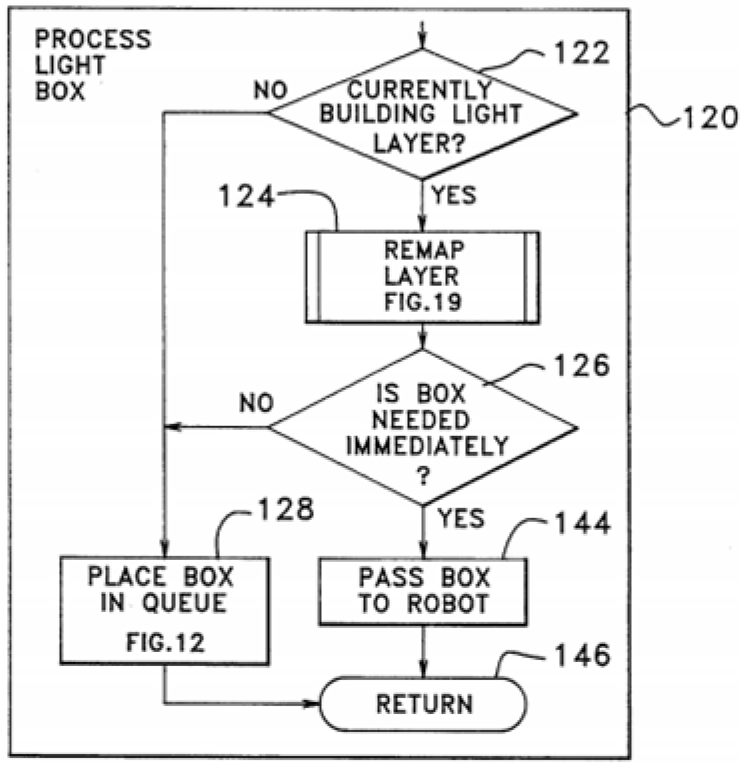

AUTOMATED PALLETIZING SYSTEM
RECEIVE PALLETIZE ORDER
102
BUILD NEW PALLET FIG.6
104
218
ANY BOXES LEFT IN ORDER?
YES
NO
220
PRINT EXCEPTION REPORT AND INVOICES
222
MORE ORDERS TO PALLETIZE ?
YES
NO
390
END
101

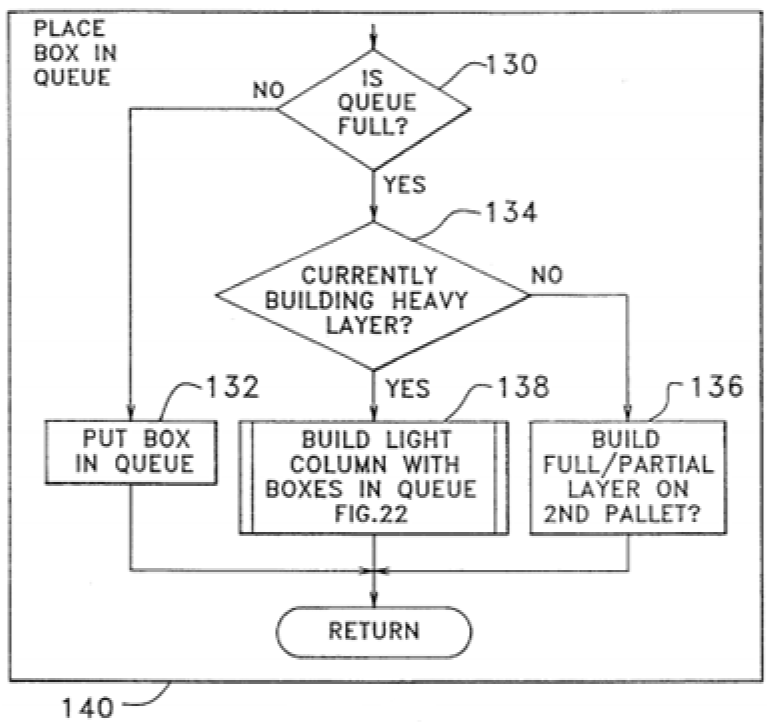

BUILD NEW PALLET
106
GET NEW PALLET
108
HEAVY BOXES LEFT ?
NO
YES
110
BUILD LAYER FIG.7
184
MAX HEIGHT/WEIGHT REACHED?
YES
NO
186
HALF OF MAX HEIGHT REACHED?
NO
YES
188
ENOUGH LIGHT BOXES TO COMPLETE PALLET ?
NO
YES
ANY BOXES LEFT IN ORDER ?
YES
NO
190
BUILD LIGHT LAYER FIG.10
192
RETURN
214
104

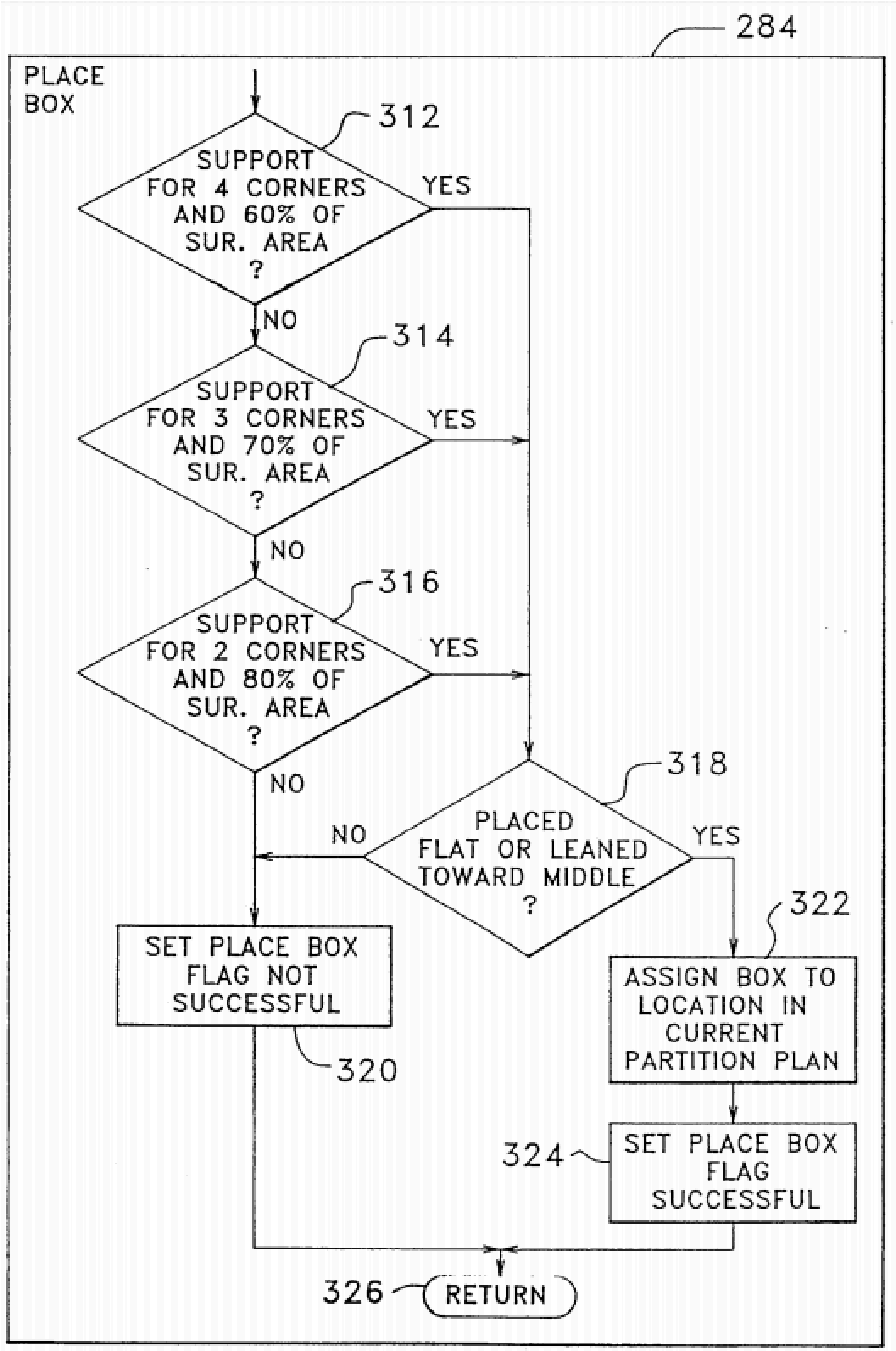

BUILD LAYER
HEAVY BOXES IN QUEUE?
112
NO
YES
114
MAP LAYER
FIG.13
116
RECEIVE NEW BOX DIMENSIONS
FIG.8
172
BOX NEEDED FROM QUEUE ?
NO
YES
174
RELEASE BOX TO ROBOT
178
NO
LAYER COMPLETE ?
YES
176
NO
MAX HEIGHT/WEIGHT REACHED ?
YES
180
RETURN
110


116
RECEIVE NEW BOX DIMENSIONS
117
REJECT BOX ?
NO
YES
118
IS BOX HEAVY ?
NO
YES
PASS BOX TO REJECT STATION
119
PROCESS LIGHT BOX FIG.11
120
PROCESS HEAVY BOX FIG.9
150
168
RETURN


PROCESS HEAVY BOX
152
CURRENTLY BUILDING HEAVY LAYER?
NO
YES
154
DOES BOX CONTAIN DRY ITEMS ?
YES
NO
156
CURRENTLY BUILDING BOTTOM LAYER?
NO
YES
150
REMAP LAYER FIG.19
124
160
IS BOX NEEDED IMMEDIATELY ?
NO
YES
128
PLACE BOX IN QUEUE FIG.12
162
PASS BOX TO ROBOT
RETURN
164

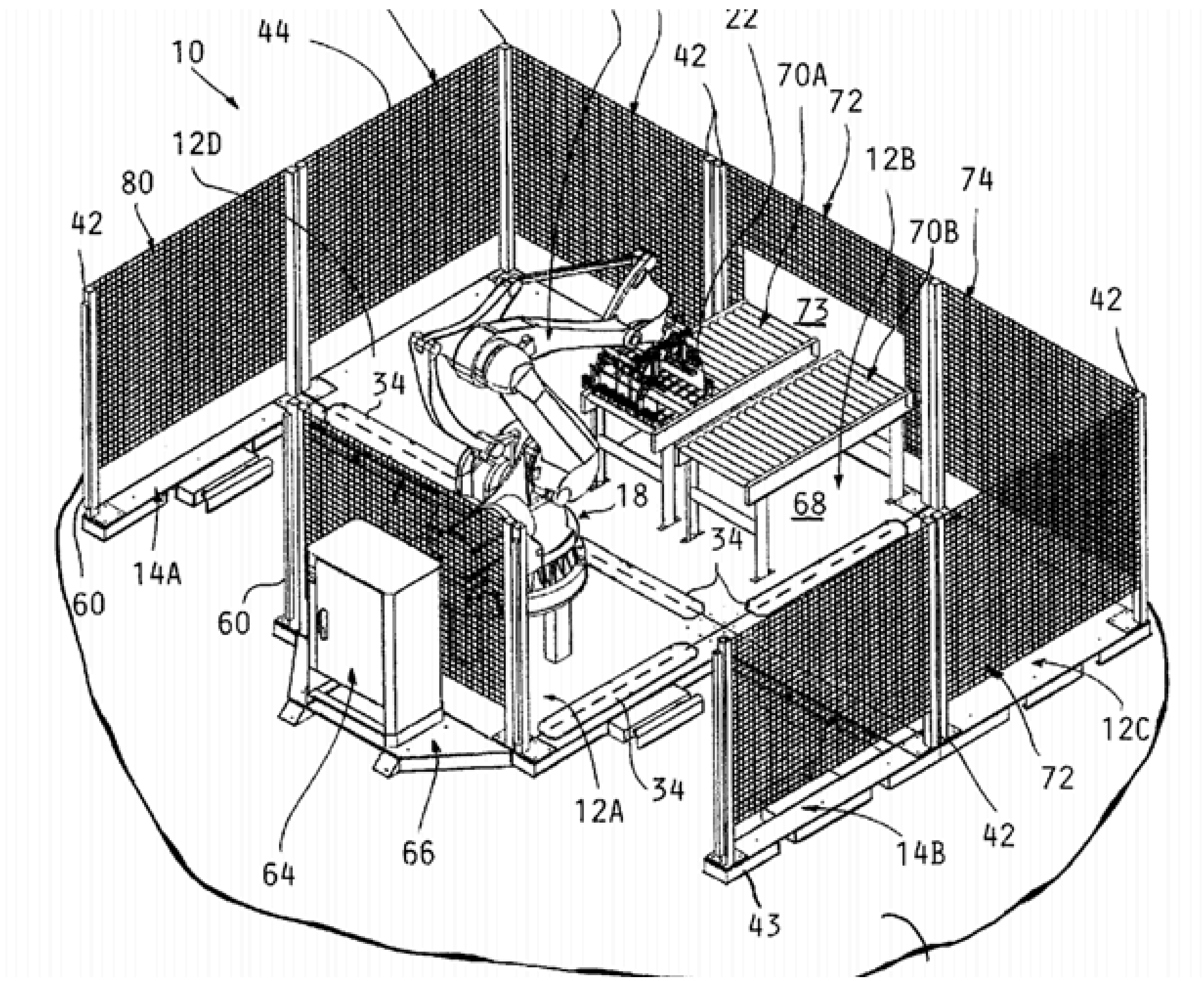

PROCESS LIGHT BOX
CURRENTLY BUILDING LIGHT LAYER?
122
120
NO
YES
124
REMAP LAYER FIG.19
IS BOX NEEDED IMMEDIATELY ?
126
NO
YES
128
144
PLACE BOX IN QUEUE FIG.12
PASS BOX TO ROBOT
146
RETURN


PLACE BOX IN QUEUE
IS QUEUE FULL?
130
NO
YES
134
CURRENTLY BUILDING HEAVY LAYER?
NO
YES
132
138
136
PUT BOX IN QUEUE
BUILD LIGHT COLUMN WITH BOXES IN QUEUE FIG.22
BUILD FULL/PARTIAL LAYER ON 2ND PALLET?
RETURN
140

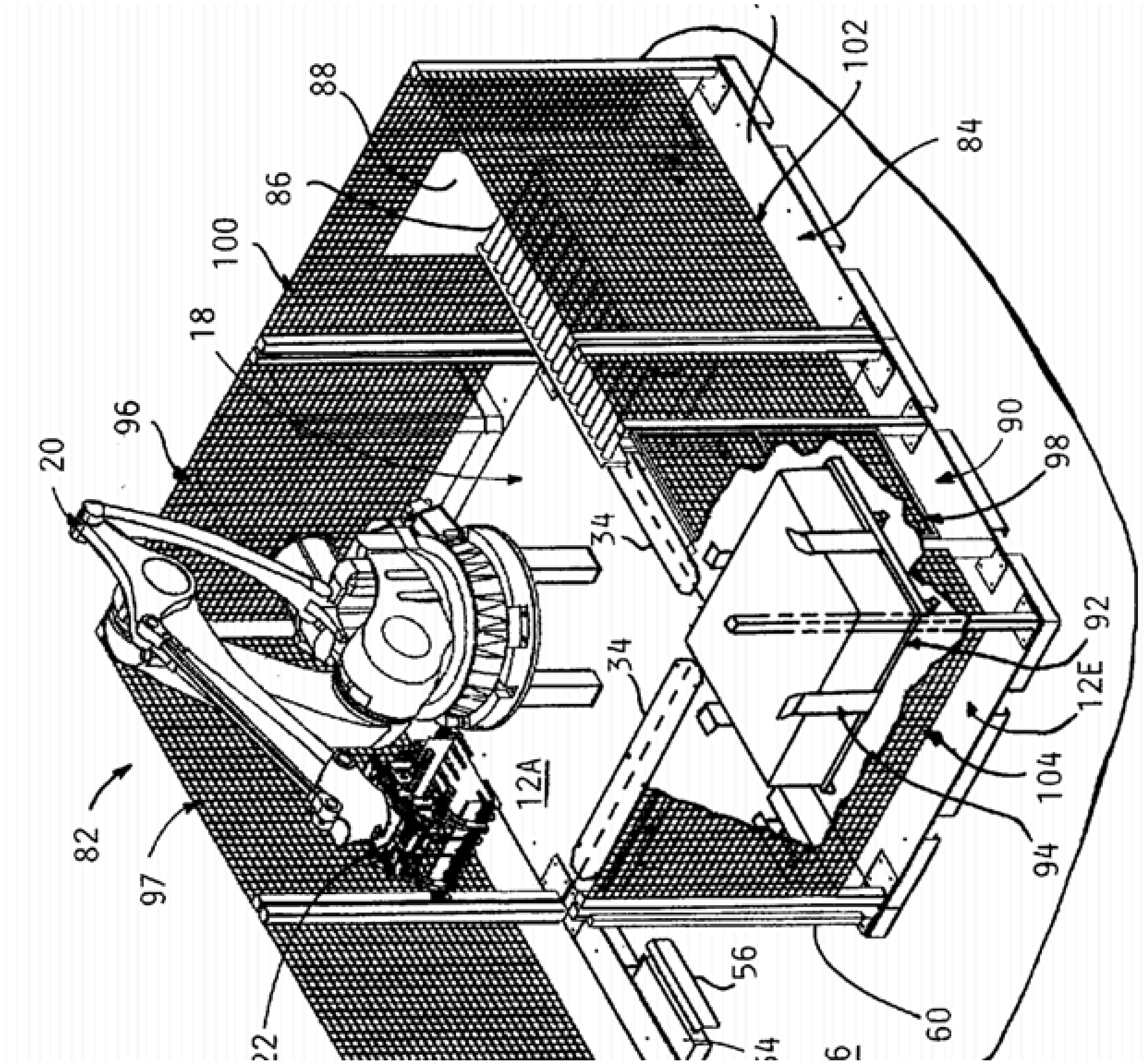

284
PLACE BOX
312
SUPPORT FOR 4 CORNERS AND 60% OF SUR. AREA ?
YES
NO
314
SUPPORT FOR 3 CORNERS AND 70% OF SUR. AREA ?
YES
NO
316
SUPPORT FOR 2 CORNERS AND 80% OF SUR. AREA ?
YES
NO
318
PLACED FLAT OR LEANED TOWARD MIDDLE ?
NO
YES
322
SET PLACE BOX FLAG NOT SUCCESSFUL
320
ASSIGN BOX TO LOCATION IN CURRENT PARTITION PLAN
324
SET PLACE BOX FLAG SUCCESSFUL
326
RETURN

Diagrams for Background Research #2

Fig. B.1: shows an outlook of a palletizer cell that is constructed according to the present invention.
Fig. B.2: represents the second configuration of a palletizer cell constructed relative to the present invention.
Fig. B.3: represents a view of a standard platform base.
Fig. B.4: shows a single pick module incorporated in the palletizer represented in figure B.2
Fig. B.5: represents view of a slip sheet module incorporated in figure B.2
Fig. B.6: shows double pick module incorporated in the palletizer cells represented in figure B.1
Fig. B.7: is a view of a platform base configuration that is adapted to be anchored to the floor and has a robot mounted on.
Fig. B.8: represents a view of a discharge module
Fig. B.9: shows a build module with a stack of pallets that has safety light curtain activated in front of the pallet.



10
44
22
42
70A
72
12D
80
12B
74
42
70B
73
42
34
42
18
68
34
14A
60
60
12C
72
12A
34
42
14B
64
66
43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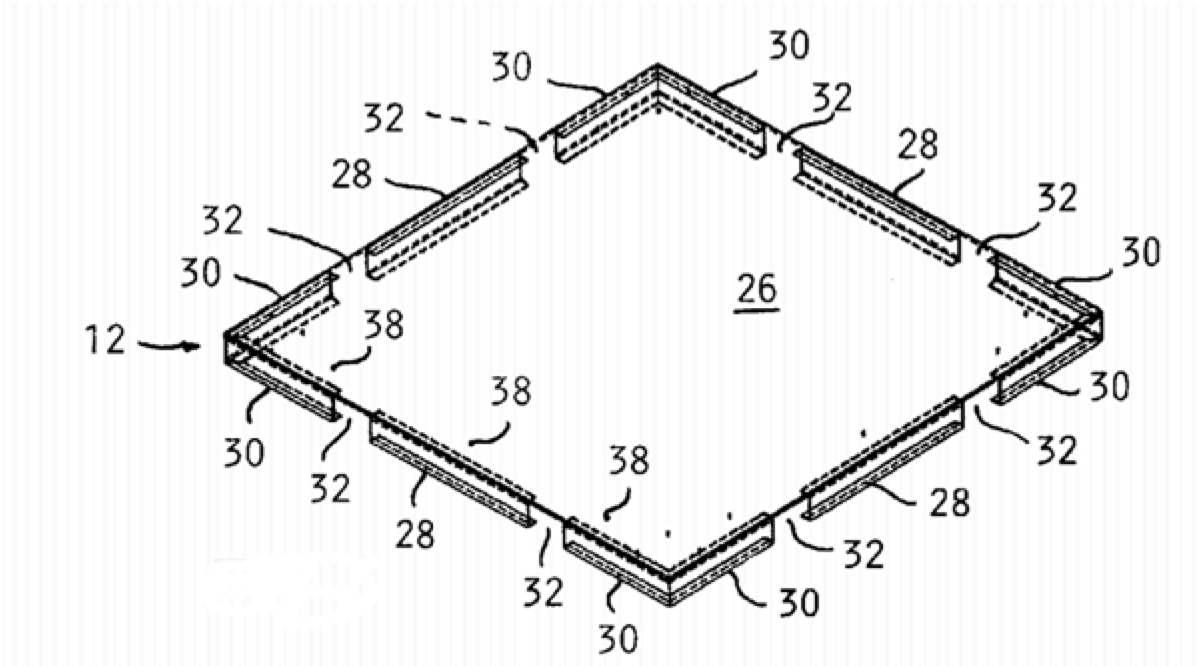
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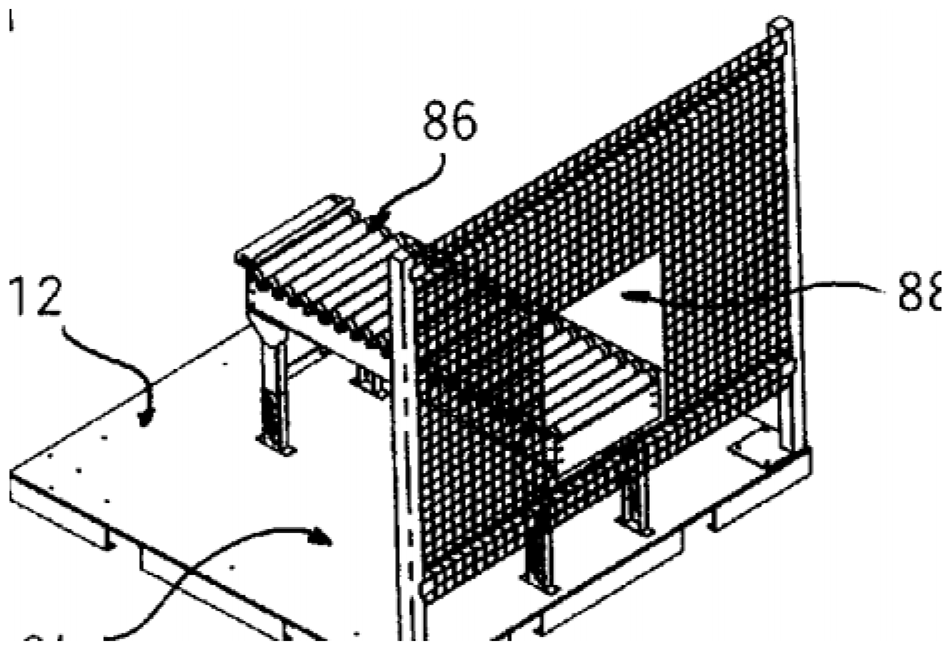
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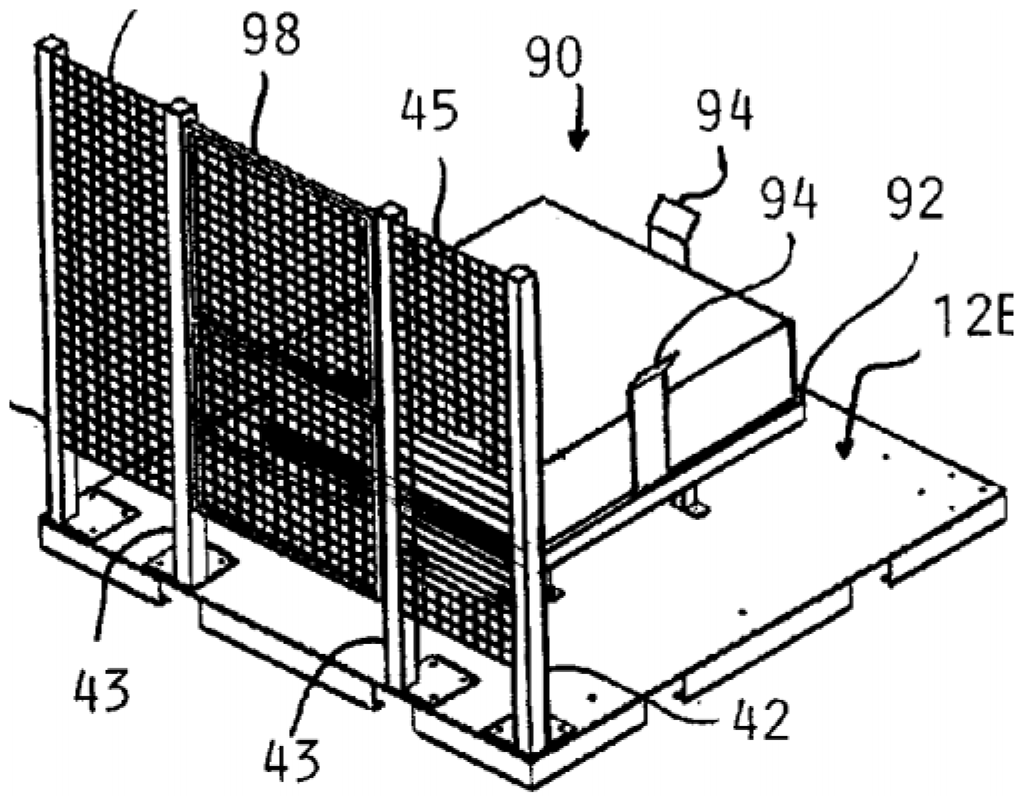
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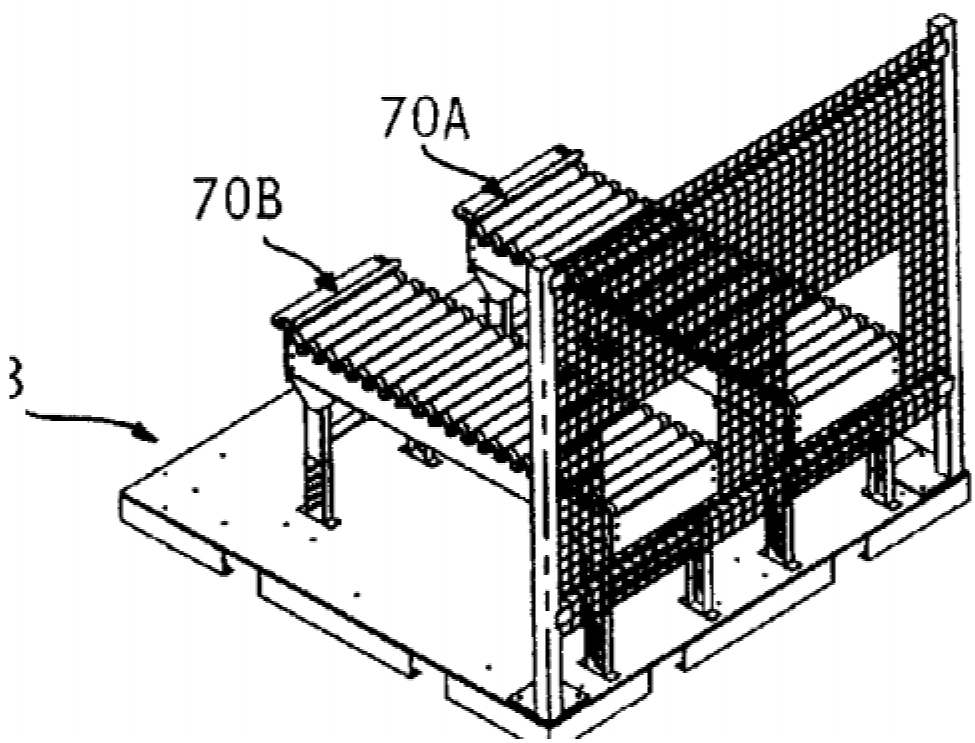
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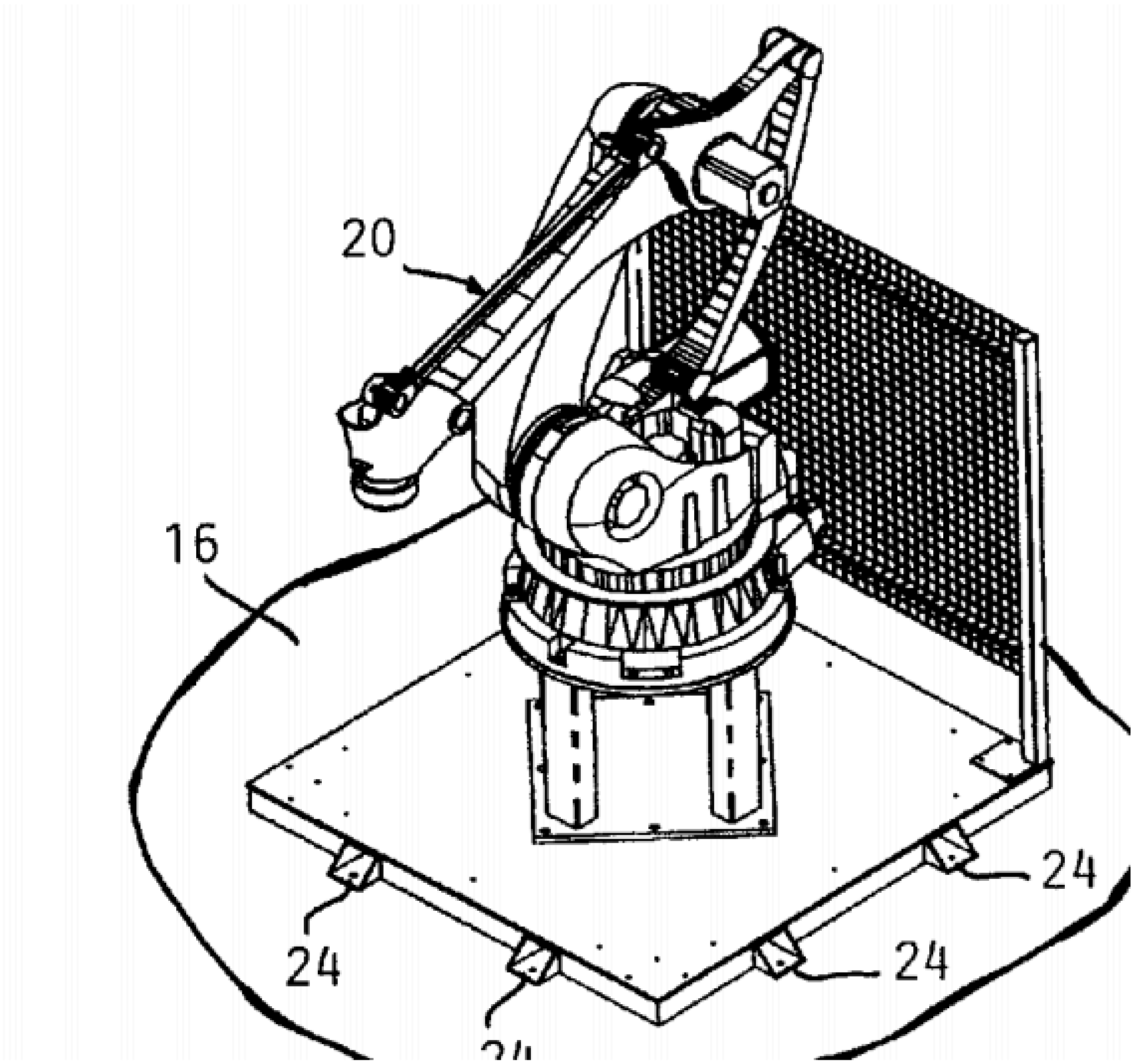
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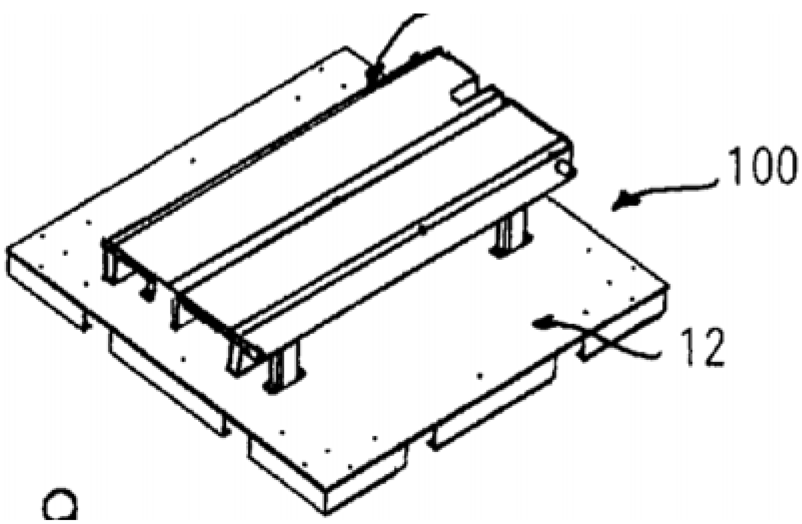
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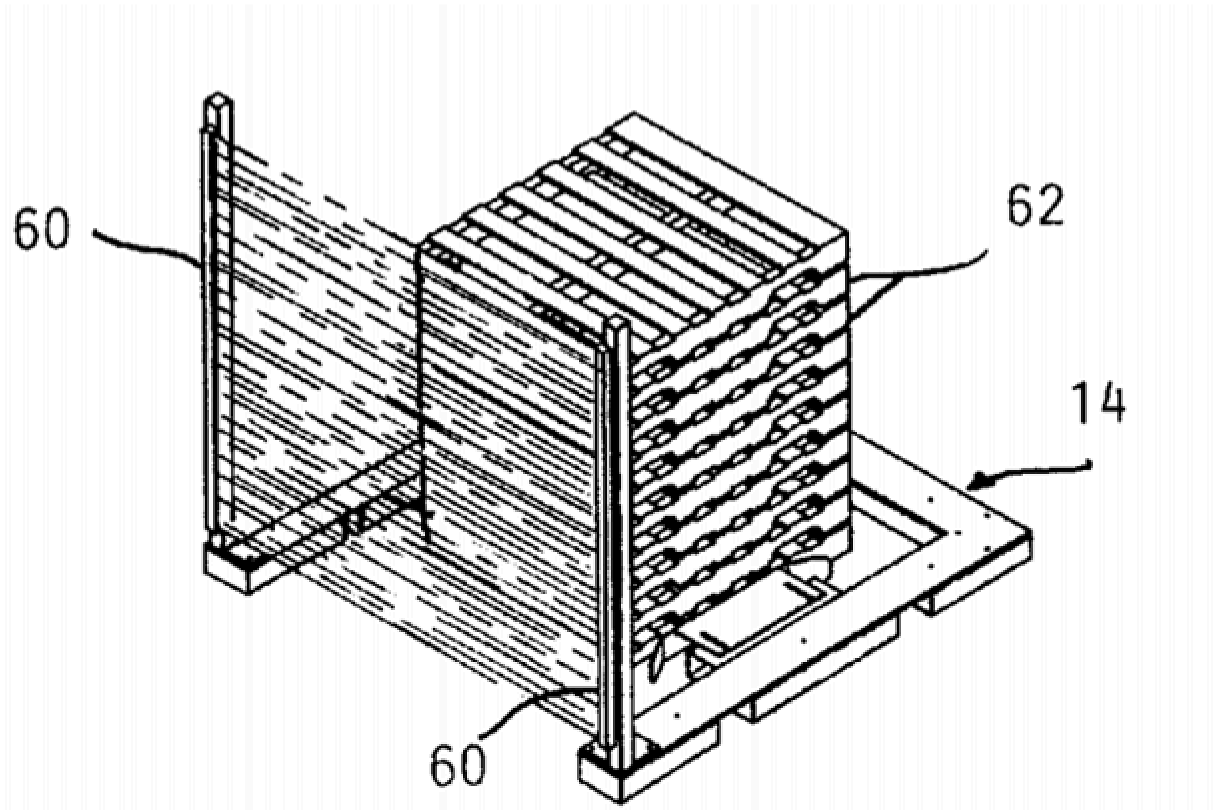

Removable Guard Operating force

Crushing or trapping points

The work cell should provide sufficient space between the robot and the boundaries of the work cell. The area to be provided is dependent on the reachable workspace of the robot in addition to a distance that is deemed suitable by the user.

Durability

The guards should be able to withstand impact.

Hygiene

The work shell should be clean and not cause hazards that relates to hygiene.

Resistant to microorganisms

Specific materials should be selected to minimize or stop the growth of microorganisms. The safeguards should also be designed to allow individuals the ability to clean the work cell easily.

Exclusion of contaminants

Electronic, chemical, and biological contaminants should be considered in the design of a work cell. The guards should prevent these contaminants from entering the work cell area. If the contaminants do appear in the area, the work cell should allow the workers to clean the contamination easily.

Resistance to Corrosion

The material used for the work cell should be resistant to corrosion and oxidation. If the desired material is not achievable a protective coating should be applied to the work cell.

Non-toxic

The work cell components should be made of materials that are non-toxic to the user.

Sharp edges and projections

The robot safeguard should not contain sharp edges or corners that can result in injury.

Integrity of Joints

The joints between each part should be able to resist forces that are applied on it.

Climbing

The work cell should prevent people from climbing the safeguard area. Following the low/high risks table for reaching over the guard in ISO 13857.

Warning Signs

If an area has the potential to put the lives of the individual at risk a warning sign should be in place to notify users.

Preventing resets

A lock or cover mechanism shall be placed on top of the safety button to prevent accidental restarts. Another alternative that can be used is having motion sensors that can detect and prevent hazards.

Span of Control

Depending on the reachable workspace of a robot the work cell should provide sufficient space for the robot to operate and perform its duties. The span of control, zone that is inaccessible due to being guarded by a locking mechanism, of a robot should be marked clearly using bright and distinct colors. If the work cell is opened the robot should stop operating until the work cell has been locked properly and the robot has been tasked to begin operations once more.

Noise

A guard shall be constructed to reduce noise leakage into the environment.

Guards (Fixed)

Removal of fixed guards

The work cell can be disassembled but will require the use of tools in order to do so. For an assembled work cell it should be sturdy and remain fixed into the position it was assembled on. The use of fixings shall be considered to prevent the work cell from being moved. Any fastening tools that can be unlocked without a tool is prohibited from use.

Positive location of guards that can be removed

Work cells that are removable should use a locking mechanism to remain in place.

Impact and Ejection Resistance

The work cell should be designed to handle potential impact due to parts that are airborne from a failed robotic operation. For viewing panels, the material shall be considered carefully such that the airborne part does not pass the work cell boundaries. The work cell should be designed to withstand both static and dynamic forces

Rigidity

Frames and supports should be selected to provide the work cell a strong, robust and stable structure that is able to endure impact without changing form.

Attachment

The work cell should be secure in place using fastening tools that is able to handle heavy loads. Different types of attachments that may be considered include welds, fasteners or clamps.

Reliability of moving parts

Parts of the work cell that allow movement should be robust against impact as well as being reliable when in use. Types of moving parts may include a hinge for the opening and closing of a work cell door.

Containment

The work cell shall contain all parts and contaminants within the area. This will prevent cross contamination from the work cell into the environment or from the environment into the working area

Electrostatic properties

A material shall be chosen that does not lead to a buildup of electrostatic charges. This is to avoid the accumulation of dust particles or cause electric shock to a person or component which may result in a fire or explosion. If the material chosen has electrostatic properties there shall be additional materials implemented to mitigate the buildup of static charge.

Guard interlocking without locks

If a workcell does not have a secure way to remain locked the robot may still operate but will cease once the work cell is detected to be open from the interlocking device. It is recommended for the work cell to have a locking mechanism to avoid consistent and abrupt stops if the work cell does not close properly

Logbook

Logbook

Group Meeting 1, Oct. 18th, 2018 (6:00 p.m to 7:00 p.m)	
Result:	First meeting for the first time, group's members get to know each other, give-and-take contact number and made group project in Facebook. Then, read out the project file, look at the required tasks to make in this project. Most of the group's members decided to do research and brainstorming for designing a robot work cell for palletizing boxes for the first week, and then decide next meeting to which work cell design we come up with and stick with an idea for this project through the semester.
Group Meeting 2, Oct. 25th, 2018 (6:00 p.m to 7:00 p.m)	

Result:	For second meeting, group's members were reading through safety standards CSA Z434, which is an industrial robots and robot systems, also CSA Z432, which is a safeguarding of machinery and applicable electrical and building codes. The goal is all group's members understand safety standards, before later on through the semester making notes on them. For next meeting, each group member will have different tasks to work on, and trying to finish them on time.
Group Meeting 3, Nov. 1st, 2018 (6:00 p.m to 7:00 p.m)	
Result:	For the third meeting, 2 more students joined the group project. Finding strengths for each student in the group, based on that, to how to divide the works and parts of the project between the group members. Also, the background search and ideas were discussed between the group's members. It was considered advantages and disadvantages for all the ideas. Decide to work on the project after finishing midterms of all group's members.
Group Meeting 4, Nov. 8th, 2018 – (6:00 p.m to 7:00 p.m)	
Result:	For the forth meeting, final concepts were debated and suggestions were considered. The robot work cell for palletizing boxes was finalised with the consensus of the group project. Decided to divide the parts of the project. - Making notes of the safety standards CSA Z434 and CSA Z432 (3 members) - Researches and making notes on the robot work cell (3 members) - CAD design, FEA analysis (2 members) - House of quality (2 members) - Logbook (1 member) More details for dividing the parts next meeting .

Group Meeting 5, Nov. 15th, 2018, (1:00 p.m to 2:00 p.m)	
Result:	Based on earlier meetings, the fifth meeting, mentioning tasks that are need to be done with deadline, each group's member has a different task to do, and each part of it had a different deadline line, to make sure that everyone follows the instructions correctly and on time. Email message was made by the leader of the group Andre Vu and sent to the group members with mentioned tasks for each students. Andre, Arjun, Waeaam and Osama sub the report tasks, while Fahad and Nigel are doing CAD design tasks, as it is shown in the picture below the Logbook. Google Document was created.
Group Meeting 6, Nov. 23rd, 2018, (6:00 p.m to 7:00 p.m)	

Result:	For the sixth meeting, it seems the group missed the objective of the project, which is to research and design a robot work cell that is able to accommodate our robots need to palletize boxes therefore, group's members tasks now has been changed and other switching the parts. Nigel will keep doing the CAD modelling, with some research on robot design patent. Also, Nigel and Andre will proper dimensions for the robot work cell. Both of Fahad and Arjun are doing research a robot work cell design patent and other tasks will be mentioned in the email message. Also Osama and Waeaam are working on research Oshawa electrical and building laws/codes, Design for Manufacturing and other tasks.
Group Meeting 7, Nov. 26th, 2018, (1:00 p.m to 2:00 p.m)	
Result:	For this meeting, were discussed about how the final report arrangement and content how it should be at the end. Checking the parts of the group members after changed the members tasks, also the FEA analysis considered. Review all the parts and editing, ask for missing parts.

Group Meeting 8, Nov. 30th, 2018, (6:00 p.m to 7:00 p.m)	
Result:	For the eighth meeting, CAD were updated. Keep updating parts, reading through the report, make sure each part is correct, editing, correct grammar and spellings. Also, Check out the CAD files, CAD drawings, and FEA analysis.
Group Meeting 9, Dec. 2nd, 2018, (6:00 p.m to 7:00 p.m)	
Result:	For this meeting, the report was checked by the group members. Recommendations for perfections within the report was edit, group members were asked to check again their parts and correct their mistakes and make few changes once needed.
Group Meeting 10, Dec. 3rd, 2018, (1:00 p.m to 2:00 p.m)	
Result:	For the final meeting, it was for final review, check the whole project, editing, formatting and the CAD files. Print the report and wait to submit it tomorrow.

Email messages

Andre Vu Nov 15, 2018, 9:58 PM

to arjun.gandhi, Fahad.Khalid, Nigel.Fluegel, Osama.Aldebasi, Waeaam.aldawood

Hey everyone,

The project is due on December 4th, we must pass the report and hand it in on time otherwise we have to redo the course. I have listed tasks for people to do and their milestones. Complete the milestones by their specified dates. Look at the rubric and make sure you fill out each criteria specified. I will update the report draft as well (will be done by the end of the weekend), listing out what questions that should be answered on the report. If there are any issues with the date or if you need guidance let me know ASAP.

Andre

- Research CSAZ434 (Due Date: November 18)
- Research parts and component for robot work cell and their life cycle (Due Date: November 21)
- Design for Safety (Due Date: November 26)
- Based on the robot design will perform an analysis from the stuff we learn in robotics (Due Date: November 30)

Arjun

- Project Management (Due Date: November 28)
- Make notes on CSAZ432 (page 1-84 based on PDF)
- Engineering B.O.M (Due Date: November 26)
- Design for Manufacturing (Due Date: November 26)

Fahad

- Assist Nigel with the CAD design.
- Assist We'am for robot work cell stuff
- Search up how the work cell will function based on Mechanical, Electrical, Fluid, Thermal analysis. (Due Date: November 26)
- Assembly and Subassembly Drawings and Detailed Design Drawings + Tolerances (Due Date: November 26)

Nigel

- Assist Fahad on the Assembly, Subassembly and Detailed Design Drawings + Tolerances
- Design the robot work cell (Due Date: November 23)
- Design the conveyor belts (Due Date: November 23)
- Perform FEA on the robot work cell design and the robot itself (Due Date: November 26)
- Perform a motion simulation on design.
- Logbook

We'am

- Do research on 3 design patents for robot work cell and write notes. (Due Date: November 21)
- Brainstorm 3 conceptual design on a robot work cell and which one is the best (improvements that can be done) (Due Date: November 21)
- Make a house of quality on the robot work cell (Due Date: November 23)
- Perform an engineering and design analysis and benchmark on the robot work cell. (Due Date: November 26)

Osama

- Make notes on CSAZ432 (page 85 – 166 based on PDF) (Due Date: November 18)
- Research 3 designs for a robot that can Pick-and-Place objects and write notes. (Due Date: November 21)
- Perform a house of quality for the robot (Due Date: November 23)
- Assist We'am for engineering and design and benchmark analysis on work cell.

Email message 1

Andre Vu Nov 23, 2018, 12:40 PM (11 days ago)

to arjun.gandhi, Fahad.Khalid, Nigel.Fluegel, Osama.Aldebasi, Waeaam.aldawood

Hey everyone,

Thank you for the work submitted thus far. Unfortunately, we have missed the objective of the project. The goal is to research and design a robot work cell that is able to accommodate our robots need to palletize boxes. Since there is not much time left (Due Date: December 4th) peoples tasks will need to be changed. I've decided to split the work to research and write notes about a robot design patent that can palletize cardboard boxes and a robot work cell design patent to 3 people. The robot work cell design patent should be our main focus point.

Nigel

I'll need Nigel to research 1 robot design patent that has a CAD model ready for us to use and research a robot work cell design patent. Nigel's research and work will be the design that we write in the report and on NX or Solidworks, whichever is preferable. I'll be working with you Nigel to get proper dimensions for the robot work cell once you found a robot design.

Fahad and Arjun

I'll also need Fahad and Arjun to research other robot design patents (these ones don't require a CAD model) and research a robot work cell design patent.

The robot design should be able to pick up a 10 kg cardboard box of 24" x 12" x 8" (LxWxH). The robot will stack the boxes on a 48" x 48" x 6" pallet, 8 boxes per layer, 6 layers high with each layer having alternate orientation. I'll need you guys to follow Element #A02 for both the robot (less focus) and its work cell (more focus), #A04 for the work cell, #A05 for robot work cell, and #A07 for the work cell. All tasks must be completed by November 28th. The CAD portion which includes model and simulation, B.O.M, Engineering Drawings and Tolerances (#A09, #A10, #A11, #B03, #B04, #B05, #B06, and #B07) will also need to be completed by Nigel and Fahad for the chosen robot arm and work cell. These tasks must be completed by November 29th.

We'am andOsama

We'am and Abo I need you guys to work together on Design Plan/Project Management (Element #A03), Design for Manufacturing (Element #A12), research Oshawa electrical and building laws/codes and work on the Logbook (Element #B01) highlighted in the marking rubric. Your work should aim for an A+ and I expect all your parts to be done by November 27th. Once your parts are complete and approved by the team you may help Nigel and Fahad with their stuff.

Andre

Element A#06 and Element #A08 will be done by me once the designs have been researched and completed

If there is any confusions or concerns, please let me know on Facebook or email me or text me at 647-300-3717. Our next meeting will be on Thursday, November 29th at 6:00 pm.

I have attached some websites that could possibly help us with the designs.

https://www.kuka.com/en-ca/products/robotics-systems/industrial-robots/palletizing-robots (Palletizing robots)
https://grabcad.com/library?page=1&time=all_time&sort=recent&query=robotic%20arm (CAD of robotic arms)
https://grabcad.com/library?page=3&softwares=solidworks&sort=most_downloaded&tags=robot (CAD of robotic arms in Solid Works)

...

Email message 2

Andre Vu Nov 28, 2018, 10:20 AM (6 days ago)
to arjun.gandhi, Fahad.Khalid, Nigel.Fluegel, Osama.Aldebasi, Waeaam.aldawood

Hello everyone,

I have talked to the T.A and he said he will be following the rubric closely to see if we have all the requirements listed. Every heading has the same weight to it. I have also highlighted sections in the reports Table of Content. Red means "Haven't started", Yellow is "work in progress/needs revision", and Green means "Complete". Thanks to the excellent work of Fahad and Arjun we have completed Background Research. A good effort has been put forth by Abo on Design Plan/Project Management, however, there are many portions that are needed to be fixed. I have addressed the issues to Abo and may require assistance from others to help him out.

Fahad
Fahad will be responsible for Functional Decomposition (Element #A07) for the final robot and robot work cell design. Work with Nigel on this and answer everything in the guideline. The final robot work cell and robot design has been attached below. Due Date: Saturday, December 1st @ 11:59 pm

Arjun
Arjun will be responsible for Concept Development and Screening/Selection (Element #A08). Work with Nigel to make sure you answer everything in that portion of the rubric. Make a decision matrix, consider environmental and economic factors, ... etc. Due Date: Saturday, December 1st @ 11:59 pm

Fahad & Arjun
You guys will work together on Engineering Specifications-Benchmarking (Element #A06). Use a house of quality similar to the one you used in Capstone. Customer Requirements can be found in the "Requirements" section of the report. House of Quality will go under Engineering Specifications-Benchmarking (Element #A06). Due Date: Saturday, December 1st @ 11:59 pm

We'am
We'am is currently finishing up Design for Manufacturing and will start on the Logbook. Depending on the quality of her section, she may work with someone else if they need help. Due Date: Friday, November 30th.

Osama
You will need to fix his Design Plan/Project Management portion. I have addressed all the issues and what needs to be done. Due Date: Saturday, December 1st.

Andre
I will look back on the Objective, Scope and Requirements to see if they are satisfactory. I am also working on Engineering and Design Analysis and Design for Safety. Due Date: End of Saturday

Email message 3a

Nigel
Nigel is currently working on building the CAD model, simulations, and will work on the Assembly + subassembly Drawings, B.O.M, FEA, and Tolerances. He will also be writing about concept generation in the report. If he needs assistance I will let everyone know ASAP. Due Date: End of Sunday latest.

We'll have a meeting tommorrow at 6 pm and discuss more about these parts, whats left, and what is expected. If there are any questions text me ASAP.

Robot Work Cell
https://www.youtube.com/watch?time_continue=63&v=apiid0MY4N0&ab_channel=LisaEitel&fbclid=IwAR1w3PT4S3rw_YfnQyFfqOnh0BStJYBCuuGU40-HkkAA0vDBNh4nFr3kW1c

Robot
https://new.abb.com/products/robotics/industrial-robots/irb-4600?fbclid=IwAR3Y3TGKMyxp9ANzSLoFwh71qXtowY7AdP3VCSc_kZsF6bv0wVgMisZ8rTo

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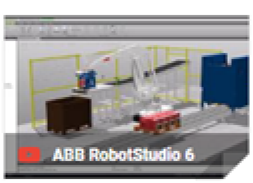
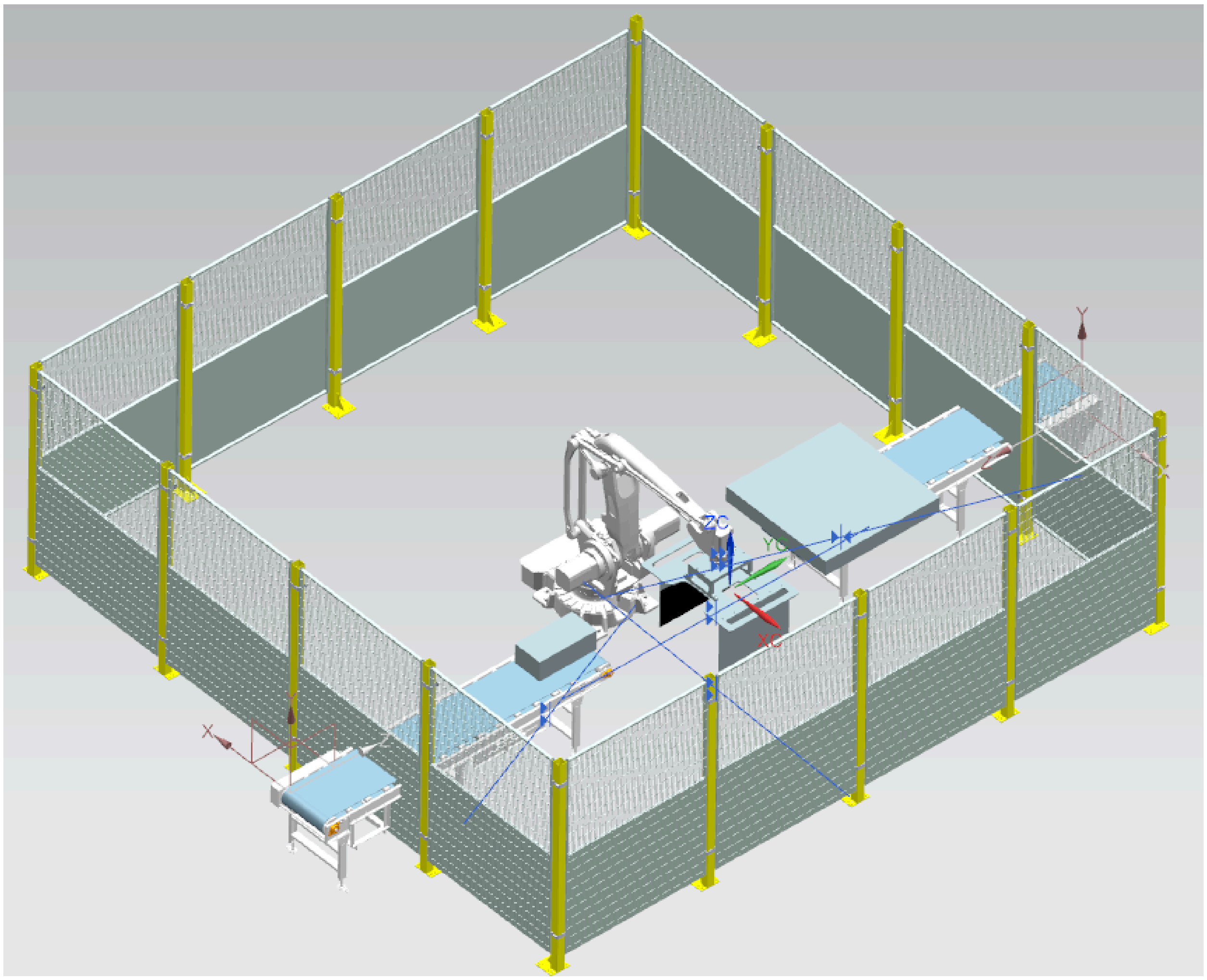
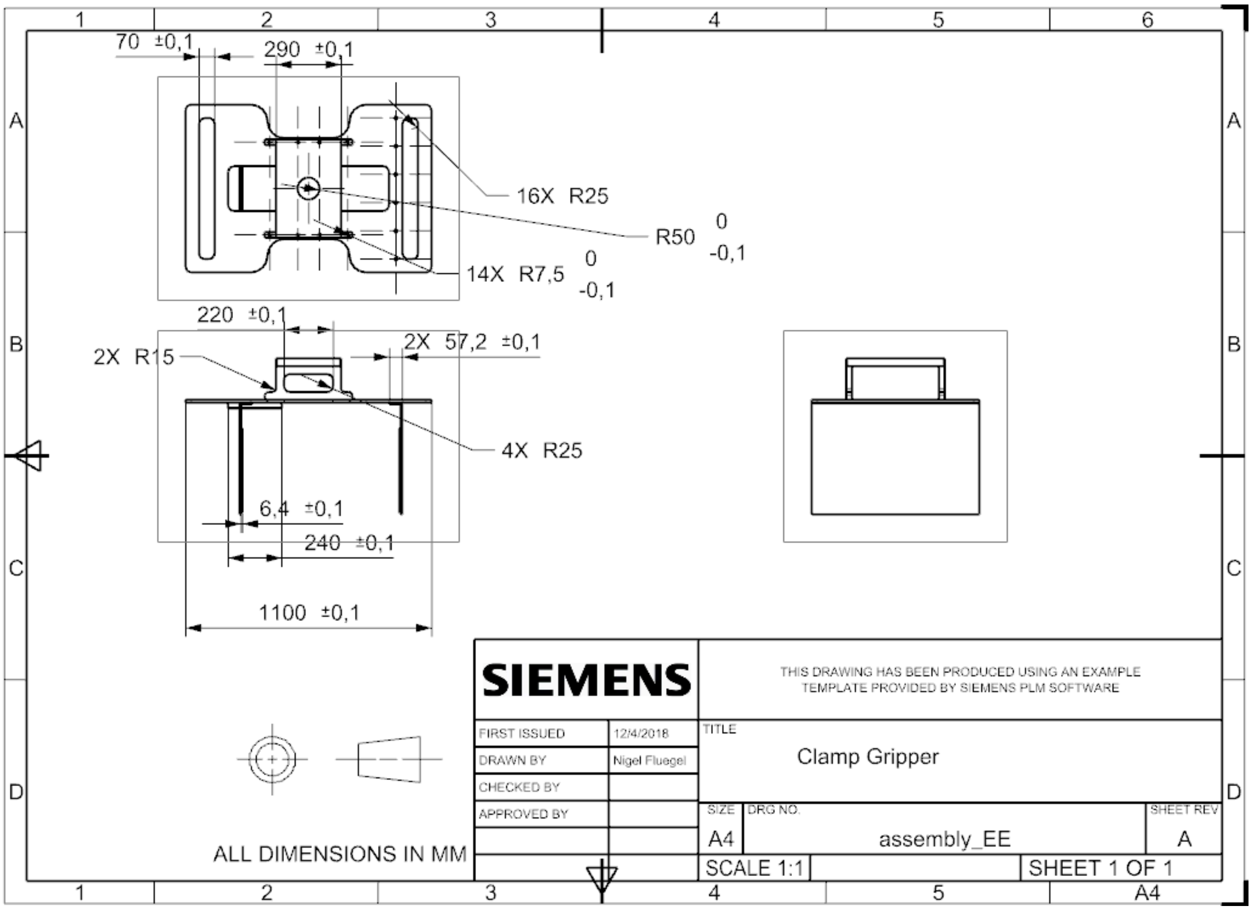


Email message 3b

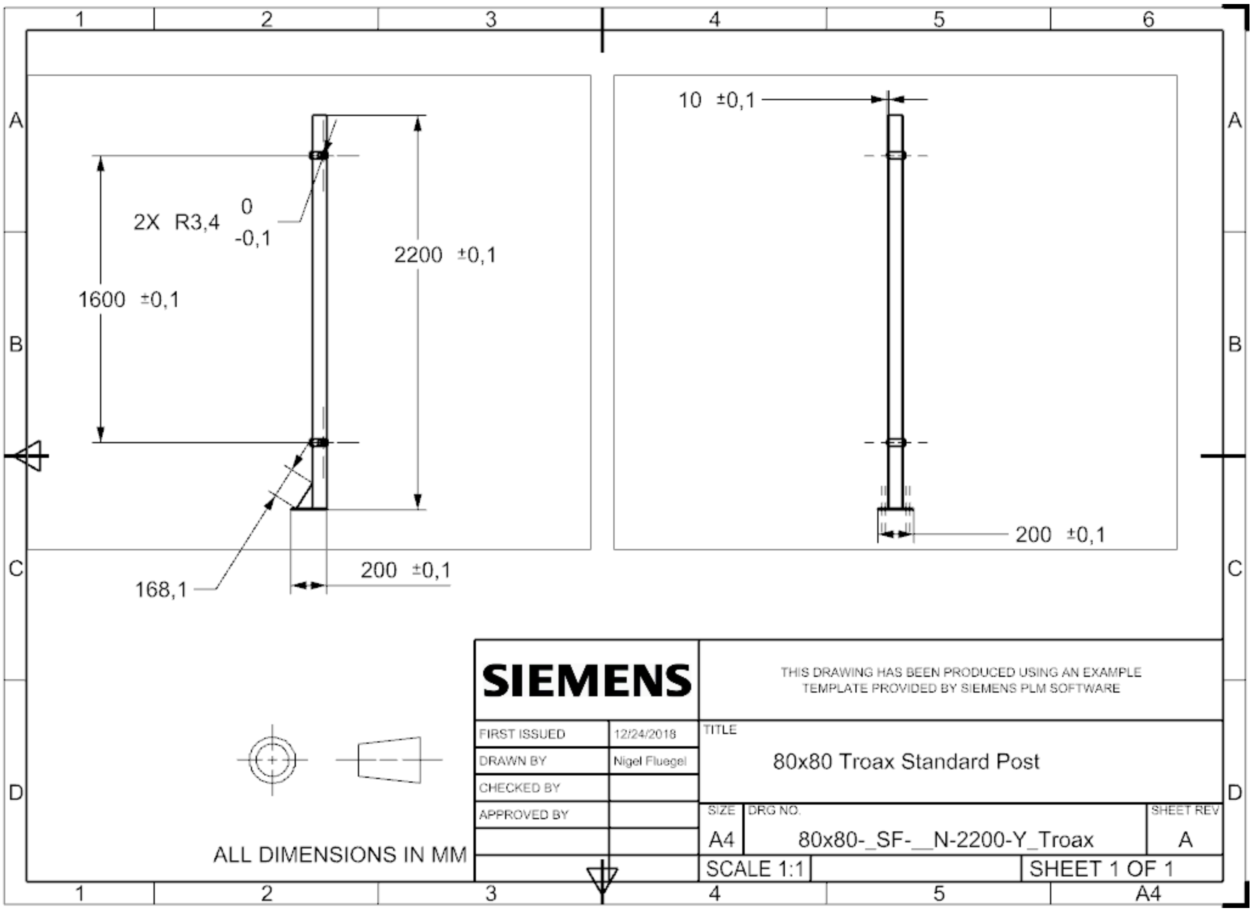
3D CAD Final Design, Drawings and Assembly



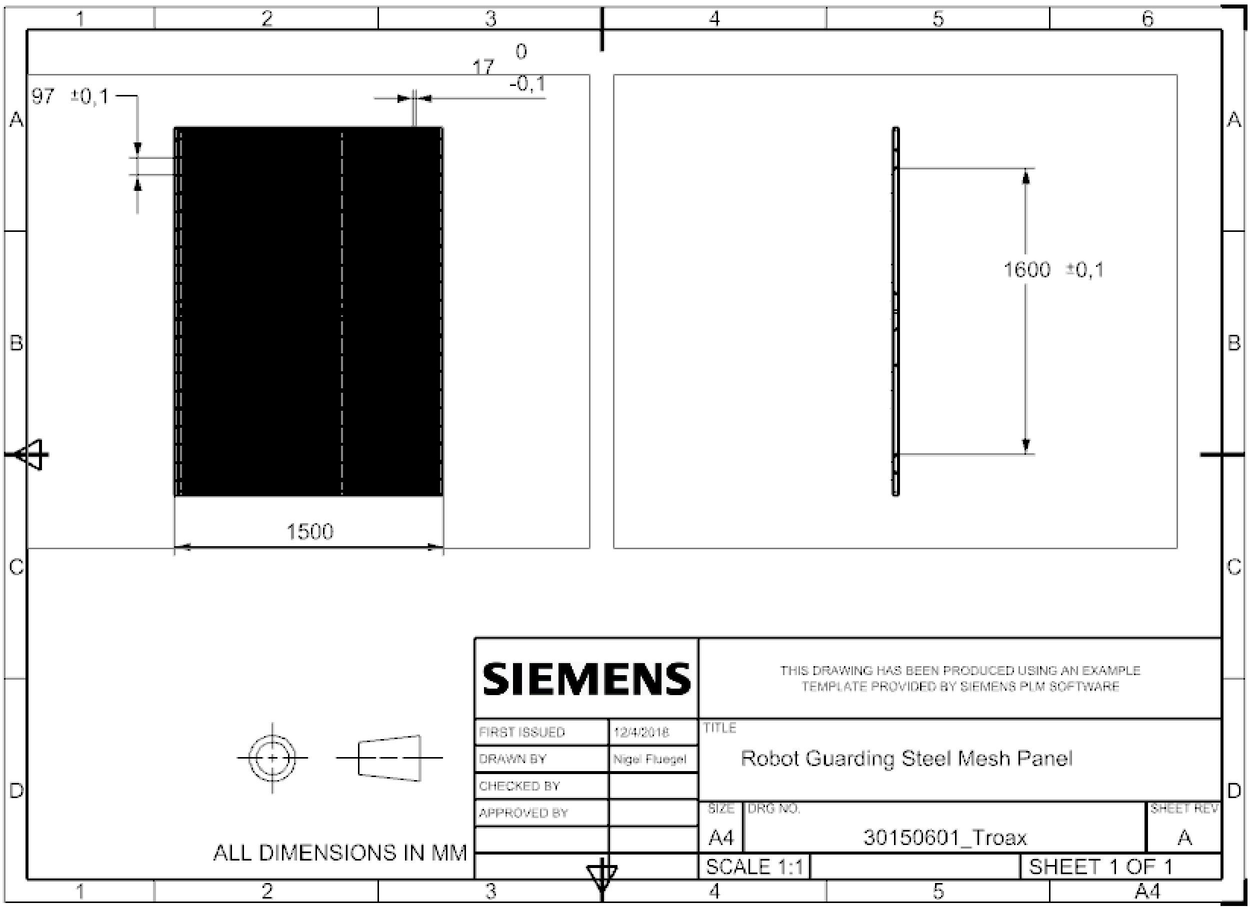
Work Cell



Clamp Gripper



Safety Guard Post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SIEMENS
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FIRST ISSUED
12/4/2018
DRAWN BY
Nigel Fluegel
CHECKED BY
APPROVED BY
TITLE
Robot Guarding Steel Mesh Panel
SIZE
A4
DRG NO.
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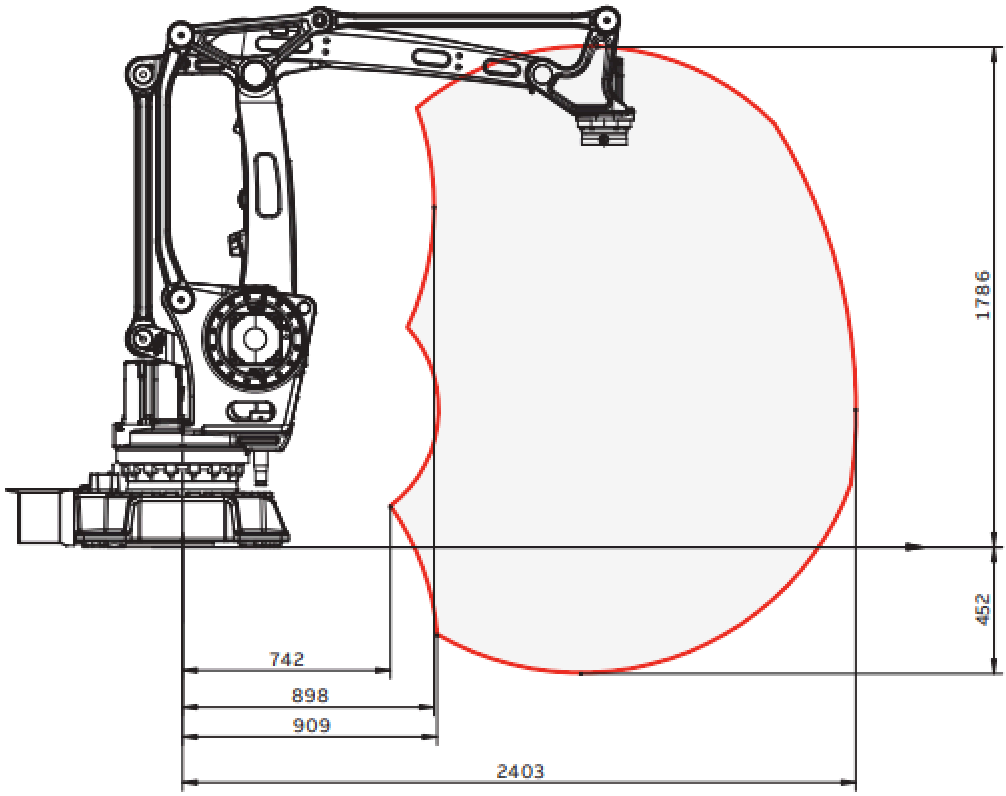
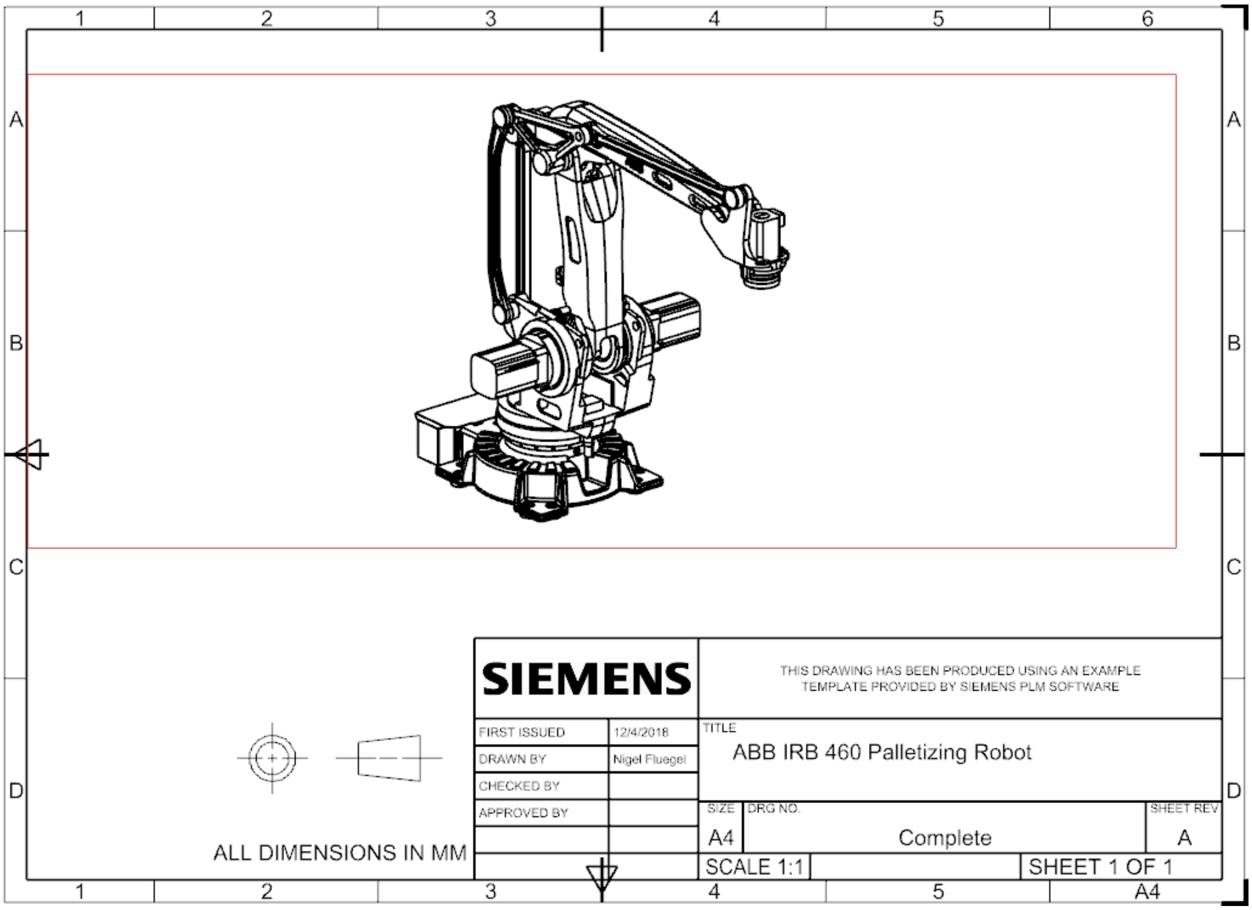
ALL DIMENSIONS IN MM

Mesh Panel

IRB 460, working range



IRB 460 Working Range



IRB 460 Drawing

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[18] Buy Drag Chain Conveyor - 3 Strand #60 - 48' Long x 48" Strand Centers
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