Seeking Smart Manufacturing Talents

The 5th Delta Advanced Automation Contest

Project Proposal

Team Number:

<table>
<tr><td>Proposal Name</td><td colspan="4">Smart Warehousing using Swarm Robotics and Machine Learning</td></tr>
<tr><td>Team Name</td><td colspan="2">Alfred and Cadbury</td><td>University/ Affiliation</td><td>Vellore Institute of Technology, Vellore, Tamil Naidu</td></tr>
<tr><td rowspan="4">Team Leader</td><td>Name</td><td>Cyril Joe Baby</td><td>Department</td><td>Electronics and Communication Engineering</td></tr>
<tr><td>Mobile</td><td>+919003772537</td><td>Post Code</td><td>632014</td></tr>
<tr><td>Email</td><td colspan="3">cyriljoe.baby2015@vit.ac.in</td></tr>
<tr><td>Address (City, State, Country)</td><td colspan="3">L330, VIT Men’s Hostel, Vellore Institute of Technology, Vellore – 632014</td></tr>
<tr><td>Member Names</td><td colspan="4">Mr. Kaushal Bajaj
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Mr. Parminder Singh Bhatia
B.Tech Production and Industrial Engineering
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</table>

Team Building

1.Cyril Joe Baby, Age 20

B. Tech Electronics and Communication

LinkedIn id: https://www.linkedin.com/in/cyril-joe-baby-767341132/

Role : Electronics and Electrical System Design, Swarm Robotics, Communication, Machine Learning and Programming

C.G.P.A: 9.02 / 10 (Up to 5th Semester)

Class 12 : 96%

Class 10 : 95%

Area of Interest : Robotics, Machine Learning, Artificial Intelligence, Embedded Systems, Industrial Automation, Computer Vision, NLP and IoT

- Software Program: AVR Atmel Studio, LabVIEW, Cadence, Multisim, Eagle PCB, MATLAB, Kiel, R Studio, Arduino IDE, CCS, Weka, Hadoop
- Programming Language: Java, Python, C, C++, MATLAB, R, Embedded C, Verilog, Ladder Logic Programming, Scala, JavaScript, HTML, Robot Operating System, PLC Coding
- Hardware: Arduino, Raspberry Pi, AVR, 8051, MSP430, Beagle Bone Black, Sensors and Actuators, Motors and Drives, PLC and HMI, Embedded and Control Systems
- Key Technical Skills: Robotics, Machine Learning, Computer Vision, Natural language Processing, Image Processing, IoT, Microcontrollers, Programming

Participated in a Hackathon at Massachusetts Institute of Technology, USA and worked on a Powered Prosthetic Leg (Bionic Leg) during the Hackathon.

Powered Prosthetic Leg Project got Second Runner Up for All India Engineering Projects Competition (INGENIUM'17) by Quest Global. This project is under incubation in association with CMC, Vellore and IIT, Madras. Patent filing and Ethical Clearance processes are going on.

Home Automation and Smart Dustbin Project won at VIT Chennai Hackathon.

Smart Wearable to detect Opioid Overdose was in Top 10 projects at hackathon by CAMTech, Massachusetts General Hospital, USA.

Attended Academic Internship by National University of Singapore at Nanyang Technological University, Singapore on Big Data Analytics and Artificial Intelligence and topped the batch with an aggregate score of 94%.

Published and Presented 8 research papers in IEEE and Springer Conferences.

Presented an idea for On-Line Sachet inspection during TECHgium, 2017 (L&T Technology)

Smarter. Greener. Together.

2. Kaushal Bajaj

B.Tech Production and Industrial Engineering

LinkedIn id: https://www.linkedin.com/in/kaushal-bajaj-7b186910a/

Role: Warehouse Simulation and Analysis, PLC and HMI Programming

C.G.P.A: 9.05 / 10 (Up to 5th Semester)

Class 12: 92.6%

Class 10: 92.2%

Area of Interest: Simulation, Supply Chain Management, Industrial Automation, Data Analysis, Robotics

- Software Program: SolidWorks, Arena Rockwell Automation, FlexSim, Simio, Minitab, Factory i/o
- Programming Language: C, C++, Python, Ladder Logic Programming, PLC Coding
- Hardware: Lath Machine, Arduino, Raspberry pi, Motors, Drivers, PLC, HMI

Presented an idea for On-Line Sachet inspection during TECHgium, 2017 (L&T Technology)

Green Belt in Six-sigma Certification endorsed by Industries like TITAN watches, Bajaj Auto.

2 research papers accepted in IEEE Conferences.

3.Parminder Singh Bhatia, Age 20

B.Tech Production and Industrial Engineering

LinkedIn id: https://www.linkedin.com/in/parminder-singh-bhatia/

Role : CAD Designing and Manufacturing, Force Analysis

C.G.P.A: 9.5 / 10 (Up to 5th Semester)

Class 12 : 90.6%

Class 10 : 9.6 / 10

Area of Interest : Designing , Supply Chain , IOT , Automation ,Simulation

- Software Program: SolidWorks, Fusion 360, Ansys Workbench, Arena
- Programming Language: C++, Python, HTML, CSS, PHP, SQL
- Hardware: Lath Machine, Arduino, Raspberry Pi

Presented an idea for On-Line Sachet inspection during TECHgium, 2017 (L&T Technology)

Motivation and Design Concept:

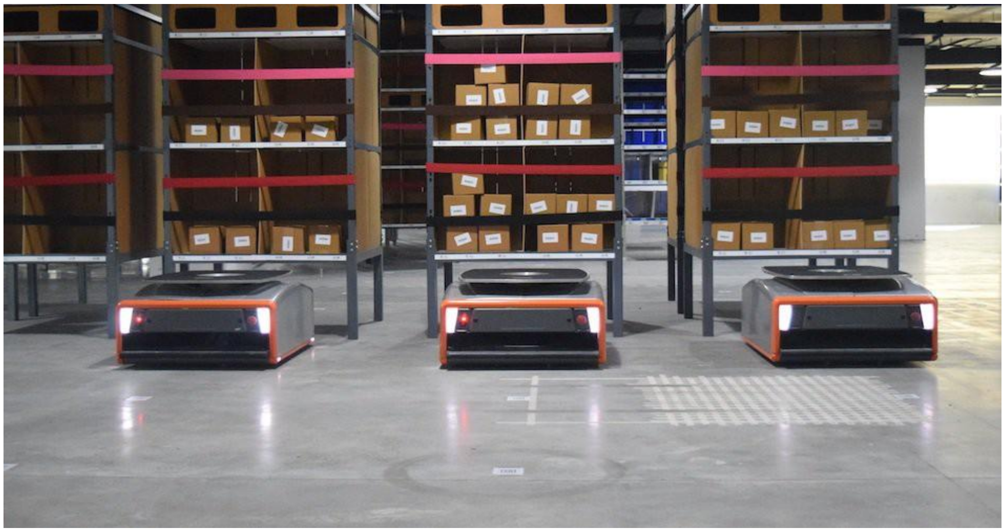
Problem Insight:

In 21st Century warehouse plays a very vital role. Today, most of the E-Commerce companies wants to ship orders as fast as possible to increase customer satisfaction. Some Companies also have Guaranteed 1-day delivery commitment but this only possible when the goods from the warehouse are retrieved and sorted for dispatch very fast. For large warehouses, hiring people for performing such activities is not a good decision instead now companies are going for Automation. There are various automation solution for warehouse but there is no solution available, which can individually pick and place order from warehouse racks to receiving or dispatching counter.

Technology Background :

Technology has changed traditional warehouse management system by altering the way companies send and receive orders. Traditional systems can be problematic because as a company′s volume order increases, the system of receiving and distributing orders becomes more complex. Companies often expand product offerings, meaning warehouse management systems must adapt to new inventory and the changing business. A poor warehouse management system drains a company′s money by not accurately keeping track of orders.

The order picking or order preparation operation is one of a logistic warehouse's processes. It consists in taking and collecting articles in a specified quantity before shipment to satisfy customers' orders. It is a basic warehousing process and has an important influence on supply chain's productivity. This makes order picking one of the most controlled logistic processes. It is one of the warehouse management system functionalities.



To achieve lower warehousing cost, accurate and faster order fulfilment, higher inventory traceability intelligent automation systems must be used. One such automated system has been utilized by Grey Orange, a smart butler as shown in the figure above, which can pick-up entire stations with multiple storage units and can move at a relatively high speed. One major disadvantage of this smart butler is that it cannot carry individual units from one place to another without carrying the entire station. This is somewhat inefficient in terms of energy spent to carry the entire stations and back in cases where only a few products are required.

Another example of intelligent automated robots is the Pick-up robot by Magazino. It is a smart bot which picks up the inventory required and places it in the shelves build within it. When its shelves are filled, it goes to the unloading station.

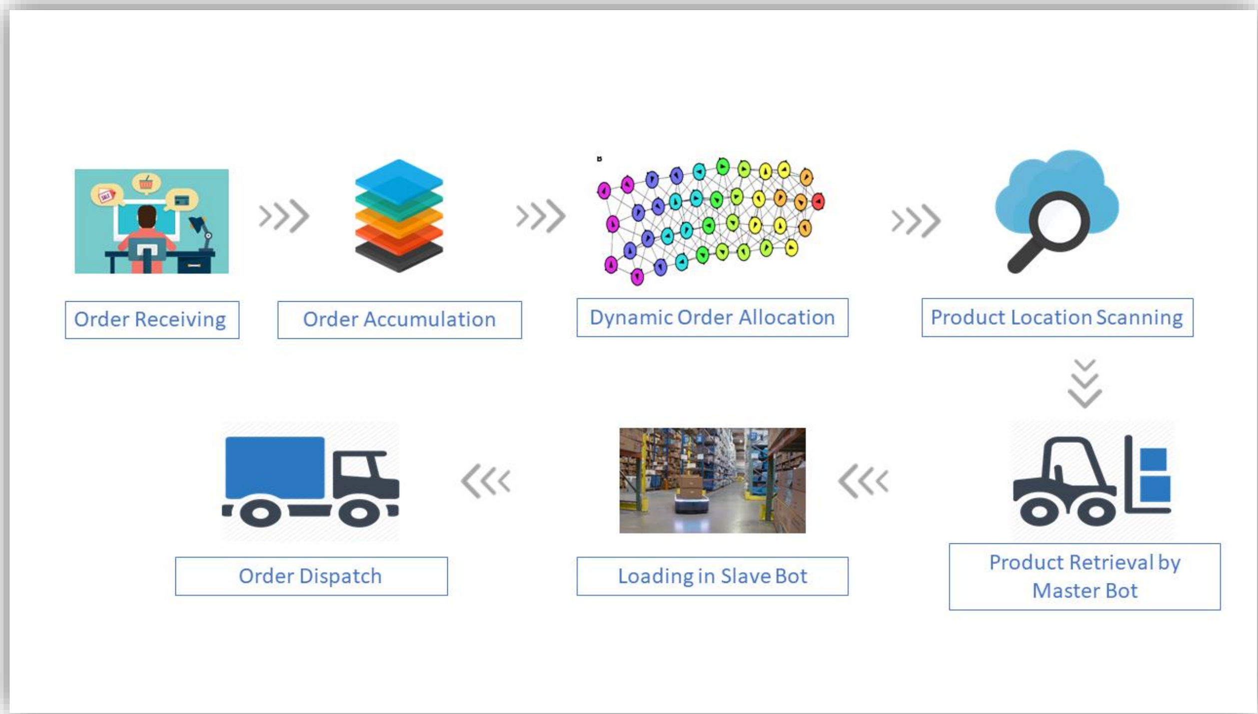
One major drawback of this design is the limited number of shelves which limit the efficiency of the bot. The bot has to unload the inventory at the unloading station at regular intervals of time, therefore this design cannot be used in a large warehouse where there would be dozens of orders to be collected simultaneously.

Project Idea:

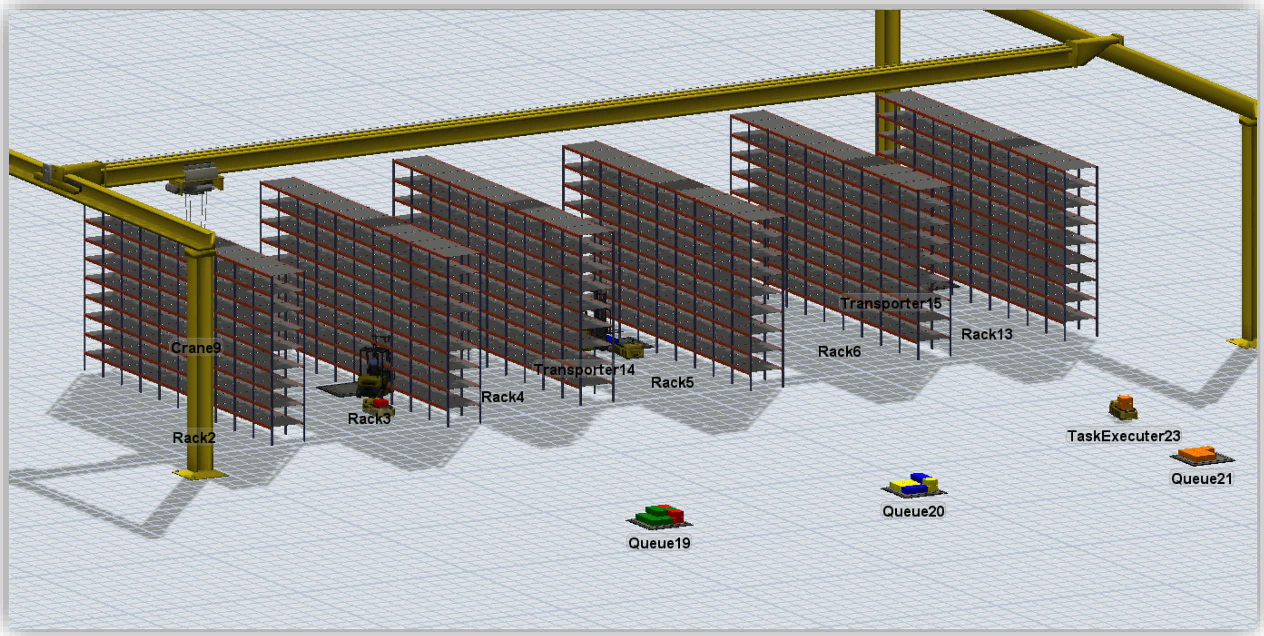
After carefully studying and analyzing the above-mentioned examples we have come up with a unique design for a smart robotic warehouse solution to cope up with high demand in minimum period of time. Our proposed design consists of two bots - Master bot and Slave bot. The Master bot as the name suggests would be the one collecting the inventory from the warehouse racks. It would collect a single unit at a time and place it in the slave bot following it. The master bot is designed to carry a maximum load of 50kg at once and can rotate a complete 360°. Once the capacity of the Slave bot is full, it leaves for unloading and another slave bot come and takes its place following the Master bot. The Master and Slave bots would be connected using swarm robotics where the Master bot would be the main bot and the Slave bots would follow it.

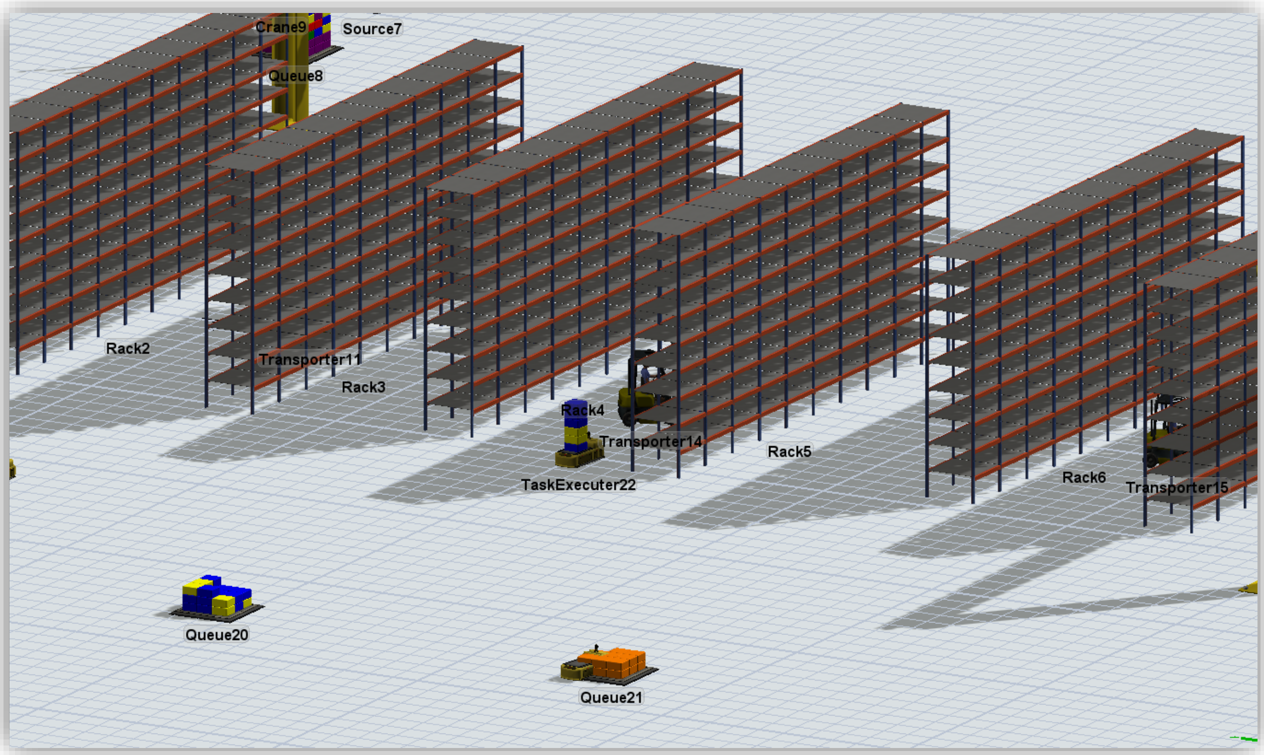
Using the Concepts of Swarm Robotics and Machine Learning, we are dynamically distributing workload among master bots. In a traditional Warehouse with Swarm Robotics, the bots are assigned predefined regions in the warehouse. Once a set of orders arrives, the job is distributed among the master bots based on the region from where it has to be collected. The disadvantage with this approach is that the bot which have less orders a lot will finish task earlier and will remain idle. This problem can be solved by dynamically distributing the task between the order.

Flow Diagram:



Given Below is a Concept Design for the proposed Warehouse system. The Master bots(Alfred) takes product from the shelves and load on the slave bots(Cadbury) and the slave bots load the products in the unloading area once its capacity is full.



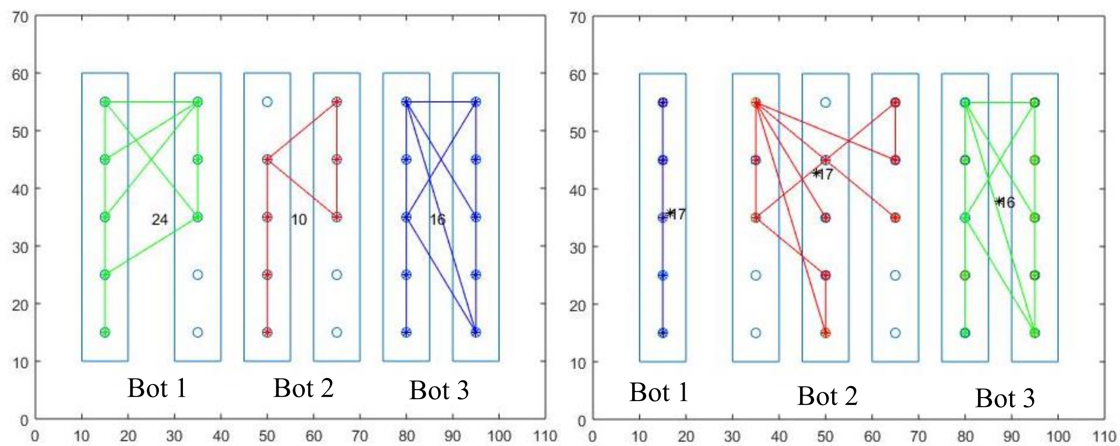


Optimization using Machine Learning

The collection of orders is done by many Master BOTs. Traditionally the Master BOTs have preassigned areas. To Optimize the warehousing solution, we have used Machine Learning (Clustering) to allocate the area to each BOT.

Example:

Traditional Optimized



We have considered two cases for simulation and analysis

1. An Order of 100 products (Warehouse with 12 shelves)
2. An Order of 50 products (Warehouse with 6 shelves)

The results of both the cases show that the optimized solution for warehousing saves time of delivery of the order and reduces the idle time of the bots.

RESULTS

Case	Number of Products in Order	Time Saved by Optimization
1	100	18 mins
2	50	8 mins

Hence our proposed algorithm optimizes the current warehousing solution in a very effective manner.

[Note: The simulation and analysis for the above result is detailed in the annexure.]

Methodology:

1. Orders are obtained
2. Once the buffer orders are reached, the set of orders are given to the BOTs.
3. The job of collecting the orders in dynamically divided among the master BOTs using Machine Learning(Clustering).
4. Each master BOT gets its own set of order to fetch.
5. A Slave BOT is allocated to each Master BOT and the Slave BOT follows the respective Master BOT to store the collected product.
6. The Master BOT goes to the respective shelves and collects and places products in the Slave BOT.
7. Once the Slave BOT's capacity is full it goes to the unloading area while another Slave BOT is deployed to follow its Master BOT.
8. Once the task is completed, the next buffer of orders is taken for execution.

Objectives/Outcome:

- Automatic Pick and place operation
- Automatic Delivery of Order
- Automatic Shelving of Stock
- Dynamic Load Distribution on Bots
- Decreasing Order Fulfillment Time
- Better Customer Satisfaction
- Warehouse Optimization

Design

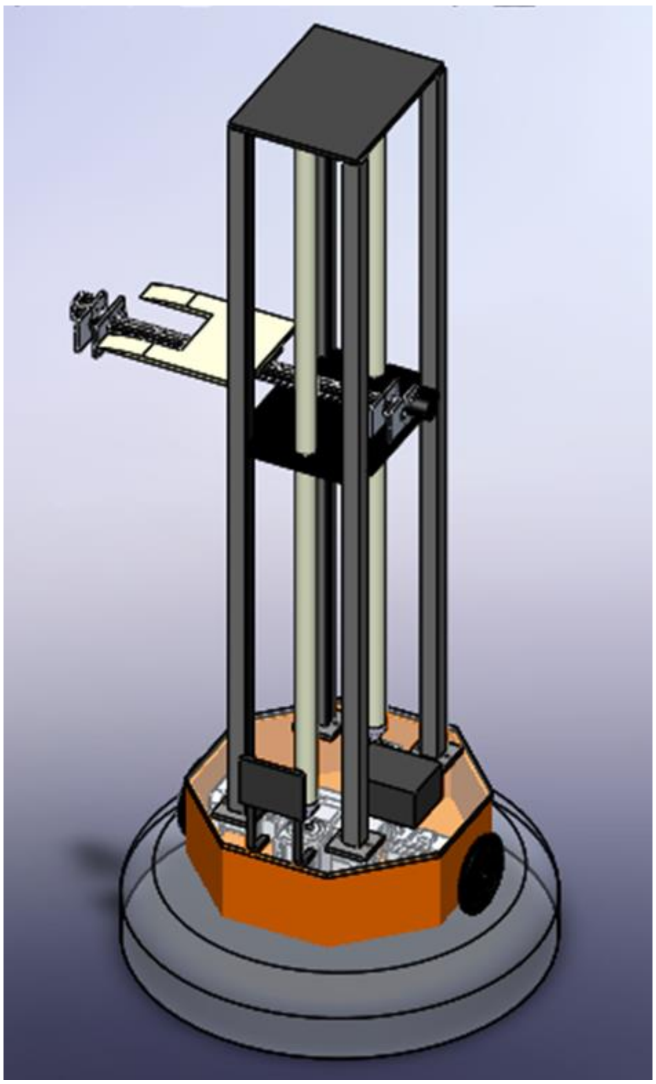


Fig: Master BOT

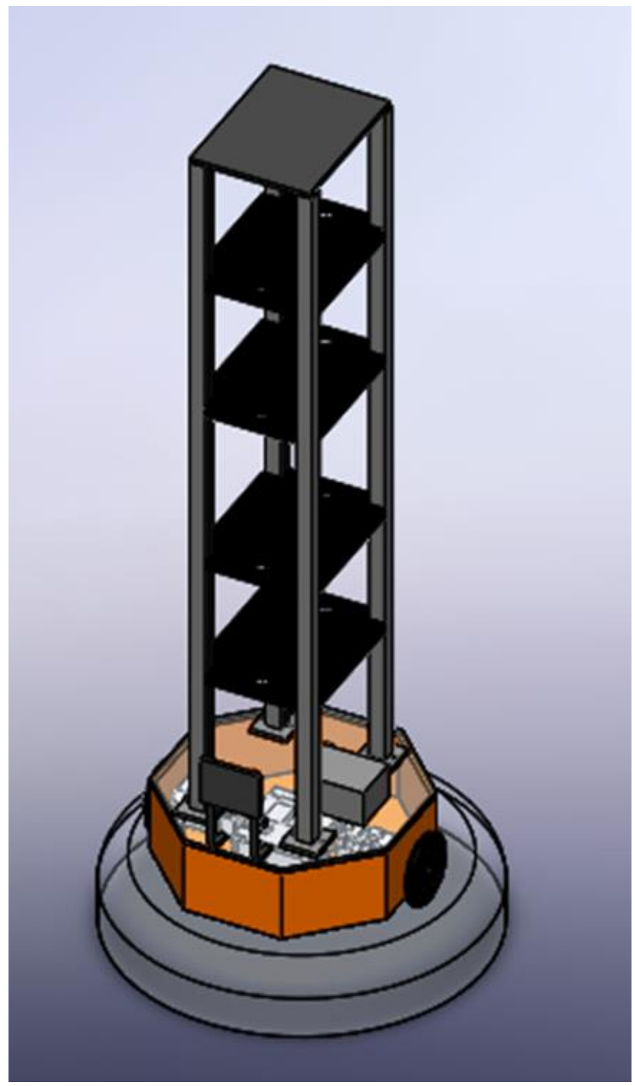


Fig: Slave BOT

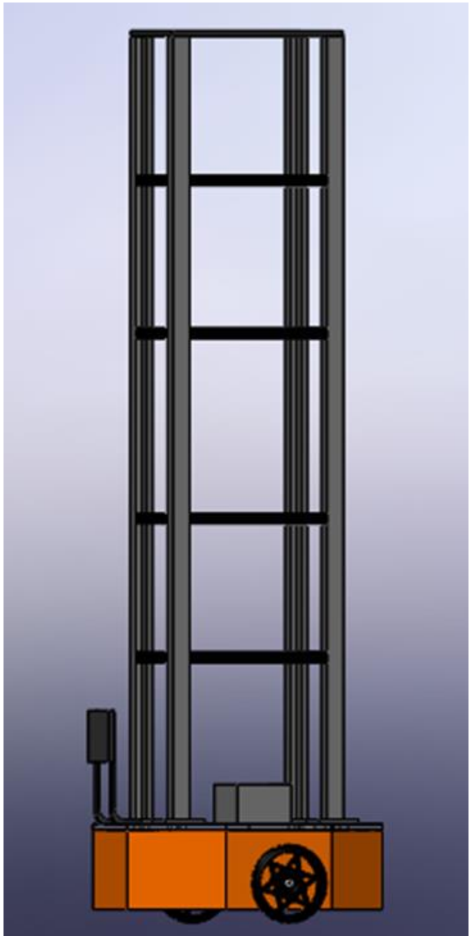


Fig: Side View of Slave BOT

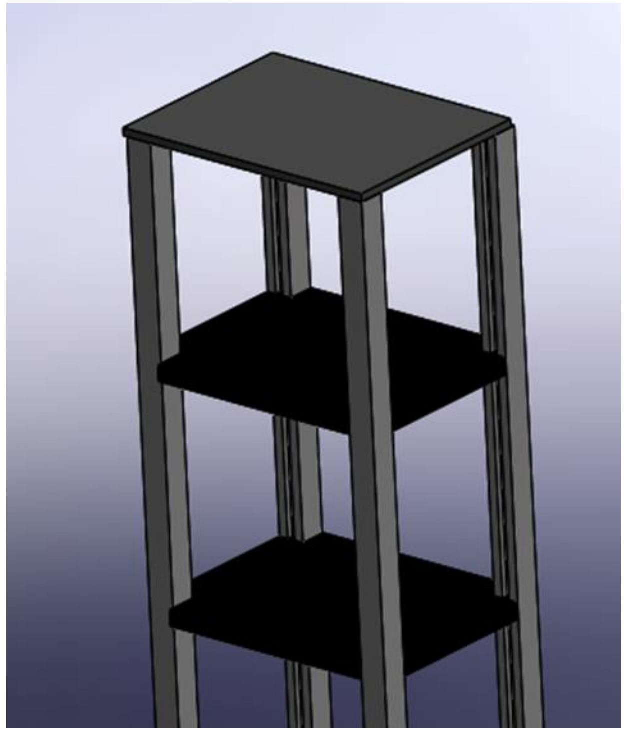


Fig: Rack of Slave BOT

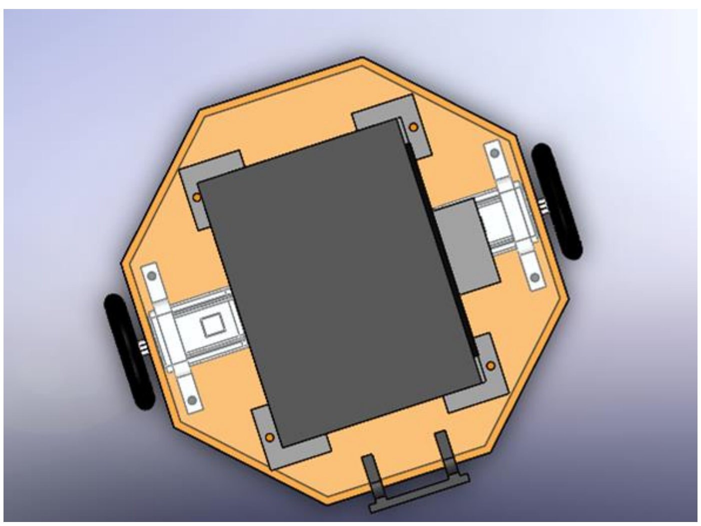


Fig: Top View of Slave BOT

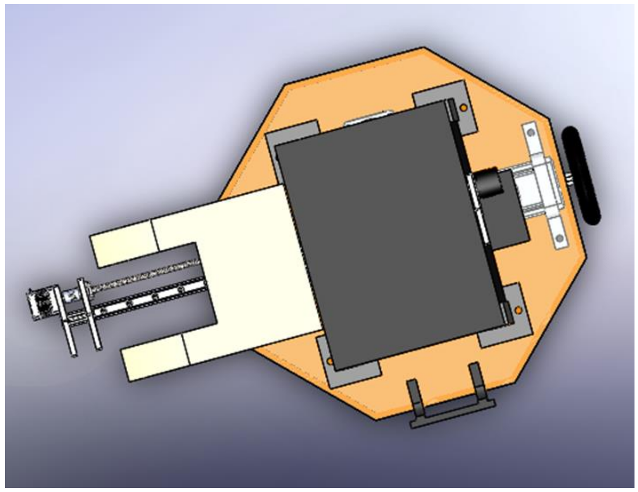


Fig: Top View of Master Bot

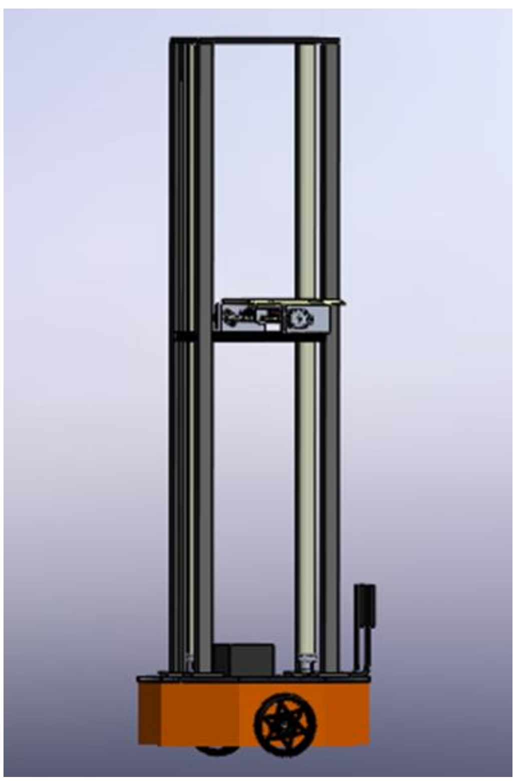


Fig: Side View of Master Bot

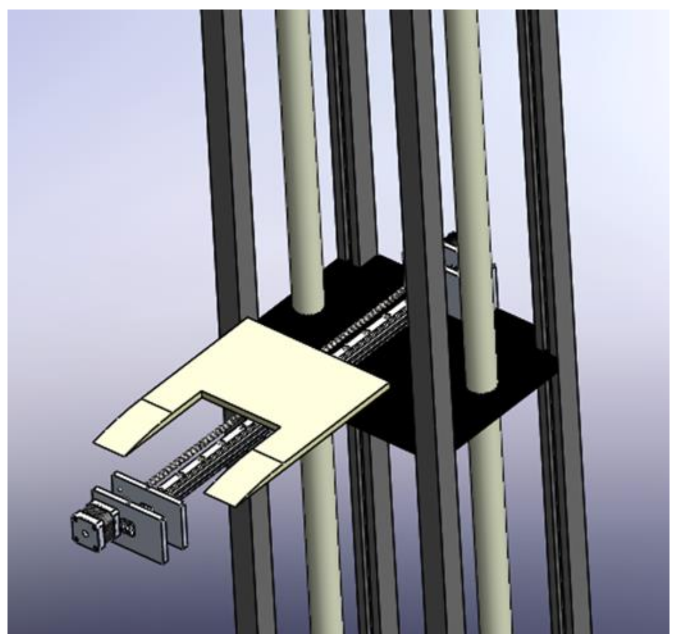
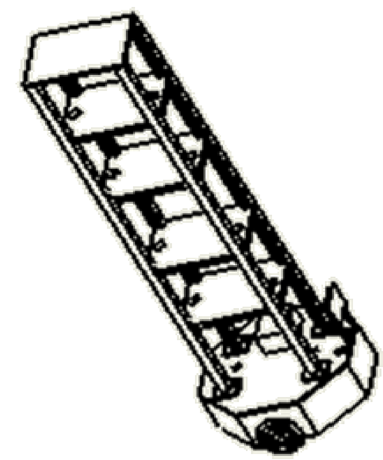
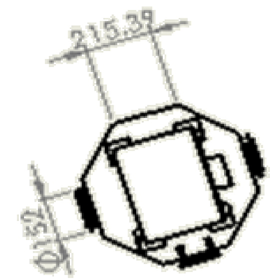


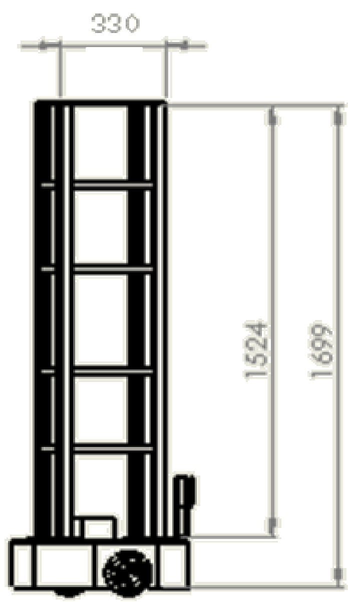
Fig: Fork of Master BOT

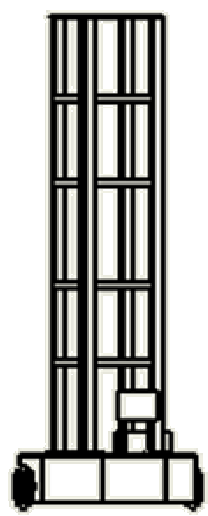
Mechanical Designs:

(All Measurement in mm)



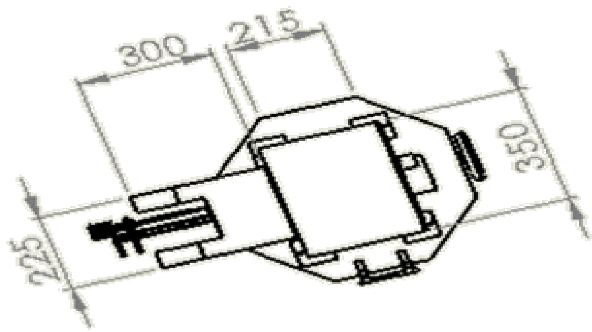


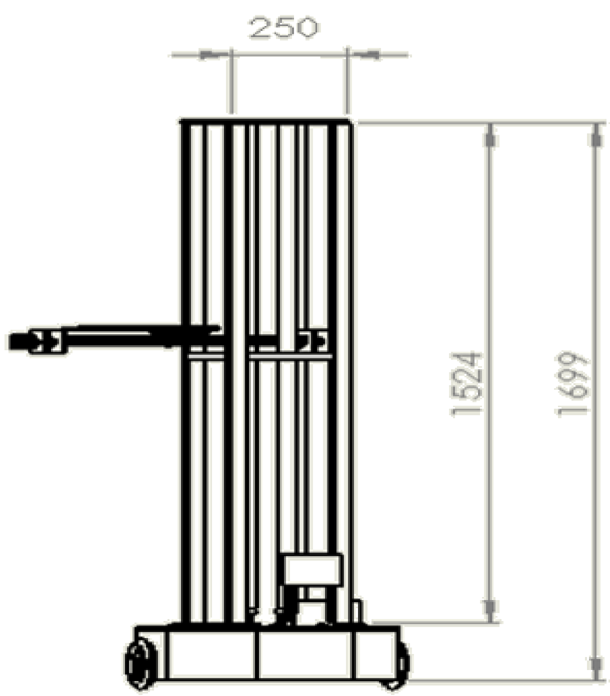




Mechanical Designs:

(All Measurement in mm)





Design Analysis:

Displacement Analysis

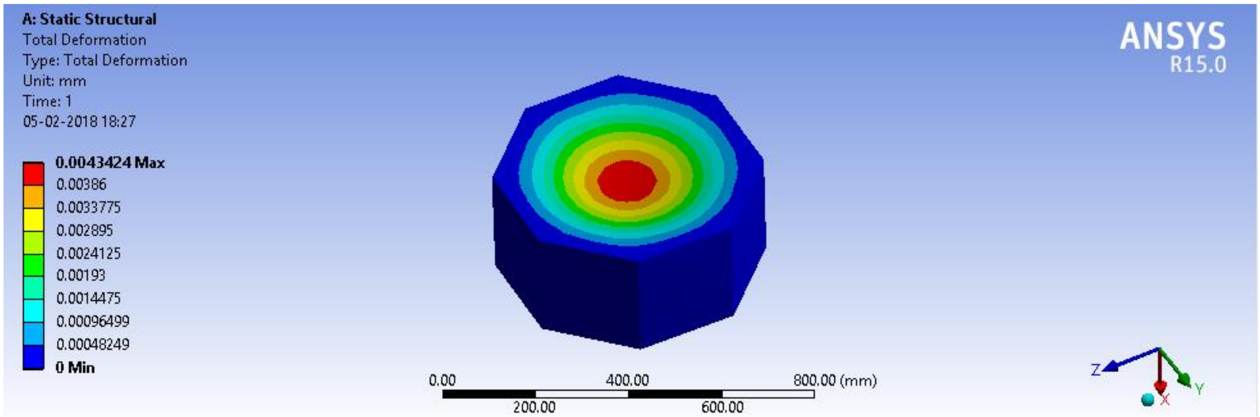


Fig: Displacement Analysis of BOT Base

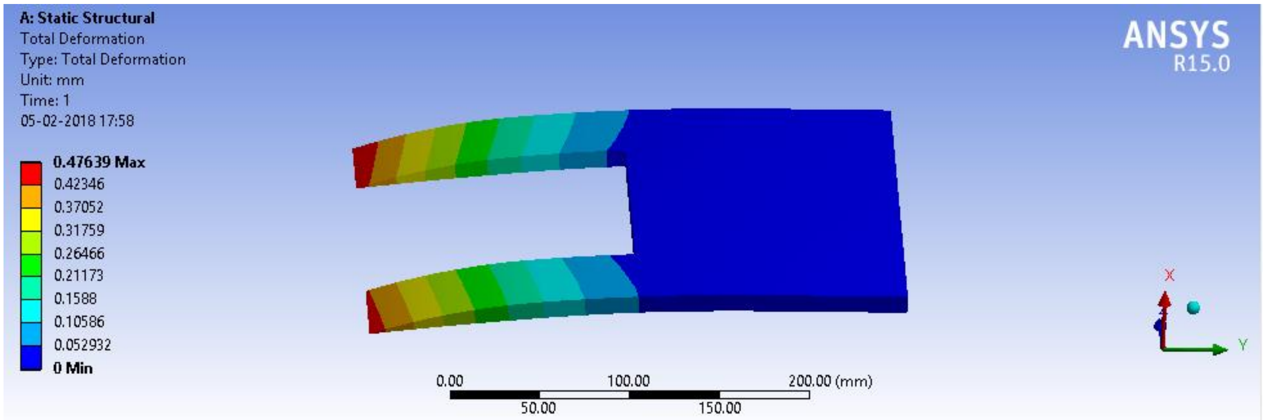


Fig: Displacement Analysis of Forklift

Stress Analysis

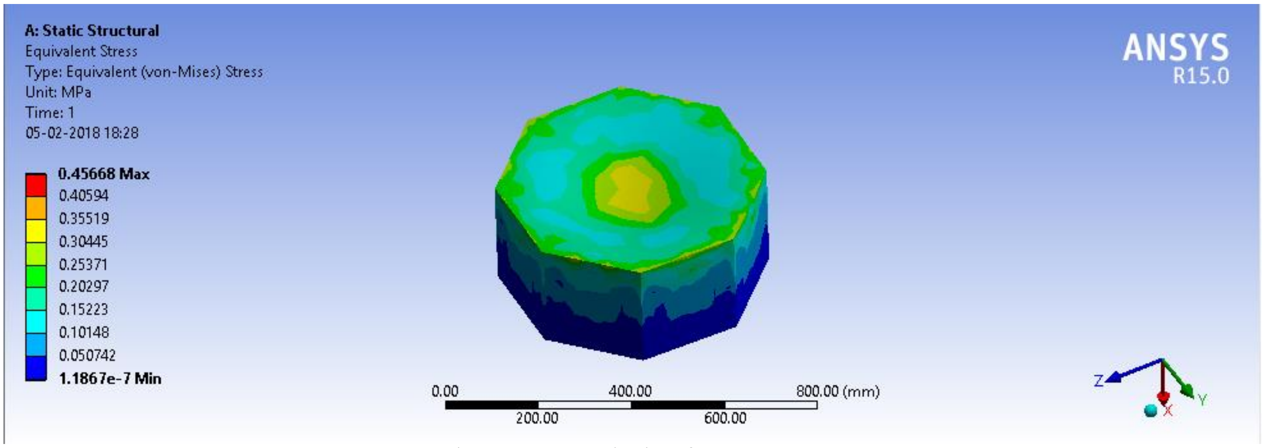


Fig: Stress Analysis of BOT Base

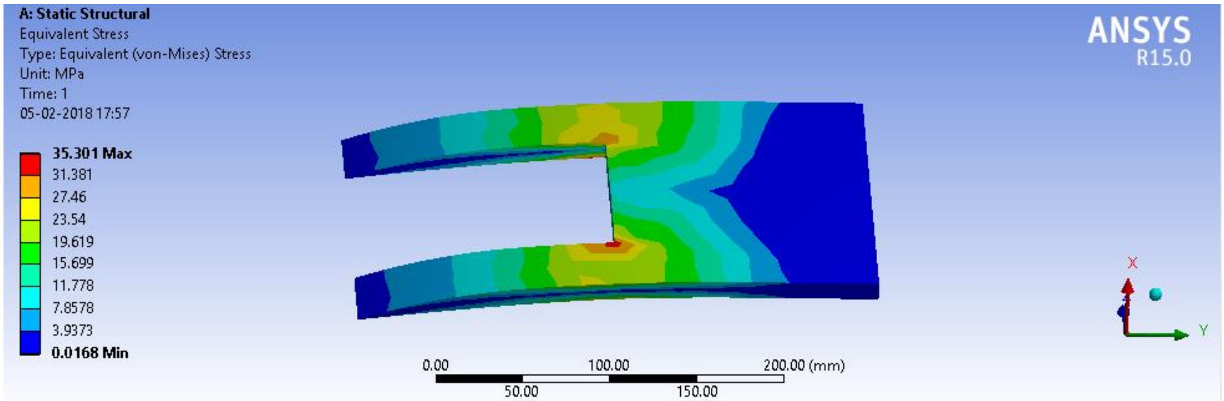


Fig: Stress Analysis of Forklift

Motion Control:

In this project we are using multiple servo motors for controlling X, Y, Z axis motion.

1. In the **X Axis** we will use **two servo motors** that gear box coupled with **two wheels** in the base of the robot that will work in coordination to move the whole robot parallel to the shelf. Feedback from **ultrasonic sensors** placed on ends of Y axis rack, facing the shelf, continuously measure distance to maintain optimum distance from the shelves.
2. In the **Y Axis** we will use **two servo motors** directly coupled to **two lead screw** and will also work in lock step / synchronization.
3. In the **Z Axis** we will use **one servo motor** to move the **forklift** near and away from the shelf.

Robot's Work Space:

- Movable Cartesian Coordinate Robot
- The robot can move anywhere in the warehouse
- Can't move on too much slanted floor (15 Degree Safe Limit)
- Cannot move pass locked door or closed door.
- Need clearance in his path for proper movement and operation.

Applications:

Case 1:

Customer Requirement: A customer wants to make a system for delivery of orders in a warehouse

Solution: Customer needs to upload the warehouse design and product locations to the mainframe system of the model and predefine the parameters needed.

Case 2:

Customer Requirement: A customer wants a system for stocking products in a warehouse.

Solution: Customer needs to upload the warehouse design and locations where the products has to be stocked in the warehouse. The location of the unloading area has to be given from where the BOTs must collect the products.

Case 3:

Customer Requirement: A customer wants to make a system for rearranging products in a warehouse

Solution: Customer has to upload warehouse design and location to the take and place the products.

Case 4:

Customer Requirement: A customer wants to make a system for delivery of books in a big library

Solution: Customer needs to upload the location of books in the library and add a feature for searching books in the HMI of the mainframe.

Case 5:

Customer Requirement: A customer wants to make a system for delivering products to the shop from the store room when the count of the particular product is low in the shop.

Solution: Customer needs to upload the location of products both in warehouse and the store room. A monitoring system has to added for the products in the shop that alerts the BOTs when the quantity is less.

Innovative Planning and Value

- Alfred and Cadbury have a unique conceptual design which increases its efficiency as compared to the butler bots available in the industry.
- The master bot Alfred can complete collecting the products quickly by avoiding unloading time in the unloading station which is done by the slave bot Cadbury.
- Alfred and Cadbury are connected using swarm robotics and continuously communicate with each other to minimize the total time spend.
- The Bots are designed using standard industrial parts and accessories (e.g.: v-slots, lead screw, etc.).

Uncertain Error Handling:

- BOT will pause all its work.
- Emergency alarm will be switched on and emergency light will be displayed.
- Massage notification will be visible on HMI and will also be uploaded on cloud.
- Robot will need operator's command to resume work after solving problem.
- Data will be logged in the mainframe storage for future use.

Cost Analysis, Reasonability and Feasibility

As we are using all parts according to the industrial standards, we are having very cost-effective structure. In this we need to manufacture only the base chassis in which we have to use milling and welding process. Thus, manufacturing time is low and will be done in a reasonable cost.

Future Scope:

1. We can modify the Master bot to increase its capacity of carrying load and the limit of the slave bots can be regulated based on the industry it is being used.
2. Using the clustering algorithm used in the bots, these bots can be used in very large warehouses to reduce the total time taken to collect the orders.
3. It can be implemented in large libraries and supermarkets for quick response and better efficiency.
4. Complete automation of warehouse using swarm robotics would result in time management of demands, as the bots are scalable, reliable and flexible.

Components Specification & Bill of Materials

Number of Master BOT: 1

Number of Slave BOT: 2

Mainframe System for Monitoring with HMI

Serial Number	Product Name	Delta Product Code	Quantity	Description
	DELTA PRODUCTS			
1	Wireless Module	DVW-W02W2-E2	4	To connect with internet
2	Power Supply (24V Output)	PMC Panel Mount Power Supply (24V Output)	4	To provide 24V to the PLC
3	PLC	DVP28SV11R2	4	Main controller which accept the input through HMI and cloud server and do control according to ladder logic.
4	HMI	DOPB07E411/415	4	To observe the status of the robots on the field and to control it, we are using 10 inches' screen.
5	Analog I/O Modules	AH04 AD-5A	3	To connect all the analog sensors like ultrasonic sensors to the PLC.
6	Motor Driver	ASD A2 Servo Drives	3	To drive all Axes motors
7	Motor Driver	ASD MR Servo Drive	3	To drive all Axes motors
8	Servo Motor with Encoder (750W)	ASDA20721U	12	To move all Axes
9	Planetary Gear Box	Delta Product	6	To attach between wheels and servo motor of X axis
10	Linear Motion Product (400W Linear Motor)	LU46214	3	For Z-Axis

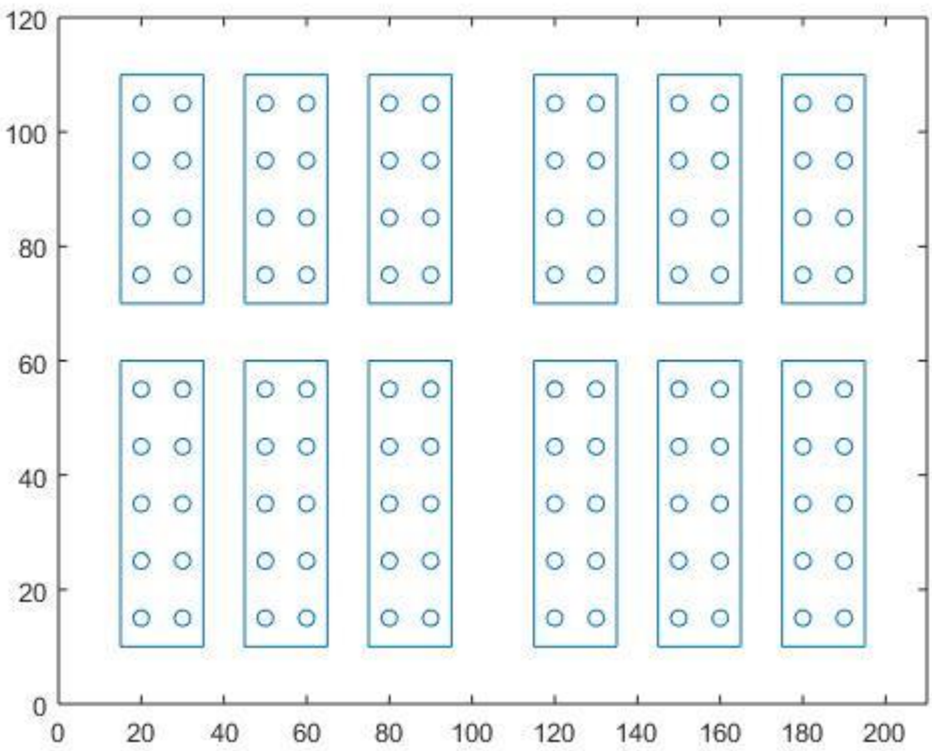
	OTHER PRODUCTS			
11	Multiple High Precision Ultrasonic Sensor	Third Party	18	For detecting objects and distance from shelf
12	Limit Switch	Third Party	12	For limiting Y Axis and Z Axis motion
13	Microprocessor	Raspberry Pi	1	For Optimization algorithm in mainframe
13	Power Supply (5V)	Third Party	4	For powering microcontrollers and other peripherals
14	Microcontroller	Arduino UNO (Third Party)	3	For sensor data acquisition in BOTs
15	Ethernet Shield for Arduino	Third Party	3	For IoT Application
16	Wheels	Third Party	6	For moving the robot along X Axis
17	Supporting Wheels	Third Party	6	For moving the robot along X Axis
18	Flexible Motor Coupler	Third Party	6	For coupling with lead screw
19	Linear Bearing	Third Party	24	For smooth movement of Y Axis rack on aluminum extrusion
20	BLDC Blower Fan	Third Party	6	For cooling Drives
21	Fastener	Third Party	Multiple	For assembly of Robot
22	Wire	Third Party	Multiple	Wiring
23	Aluminum 6063 T6 Extrusion 6 Feet	Third Party	12	For construction of Y axis
24	Wire Connector	Third Party	Multiple	Wiring
25	Aluminum L Joints	Third Party	72	For construction of Y axis
26	Lead Screw 16mm Diameter 4mm Pitch	Third Party	6	For Y axis
27	Bearings	Third Party	Multiple	For putting with rotary parts
28	Aluminum Plates	Third Party	10	For the shelves in the Slave BOT and Forklift in Master BOT
29	Nuts and Bots	Third Party	Multiple	Miscellaneous
30	Spacers and Washers	Third Party	Multiple	Miscellaneous

Simulation and Analysis

Case 1:

Scenario: A warehouse with 108 products shelved in 12 two sided shelves.

Environment



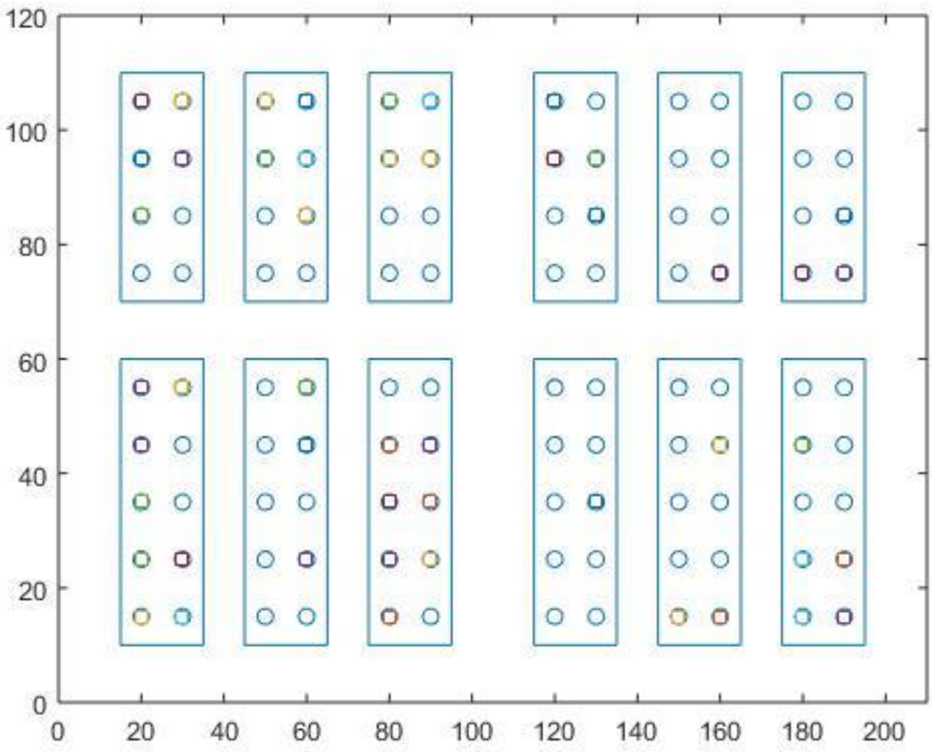
Environment Details

Number of Bots: 4 (Master bots)

Simulation: An order of 100 products

- An order of 100 products was randomly generated
- 4 bots to pick up the products for the order
- 12 shelves with a total of 108 products

An Order of 100 products

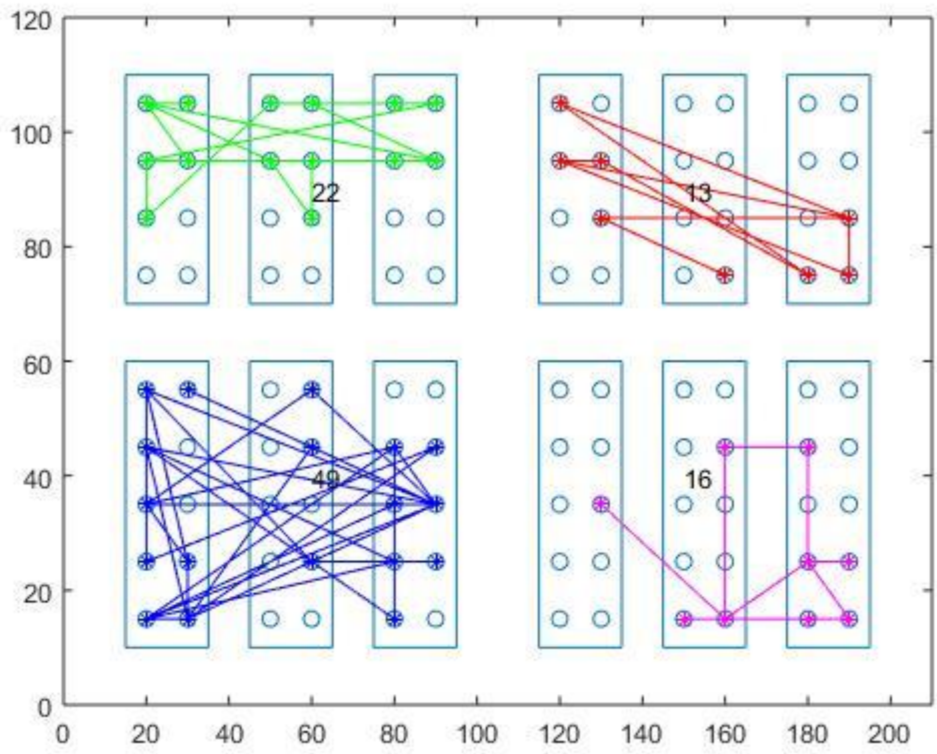


Traditional Warehousing

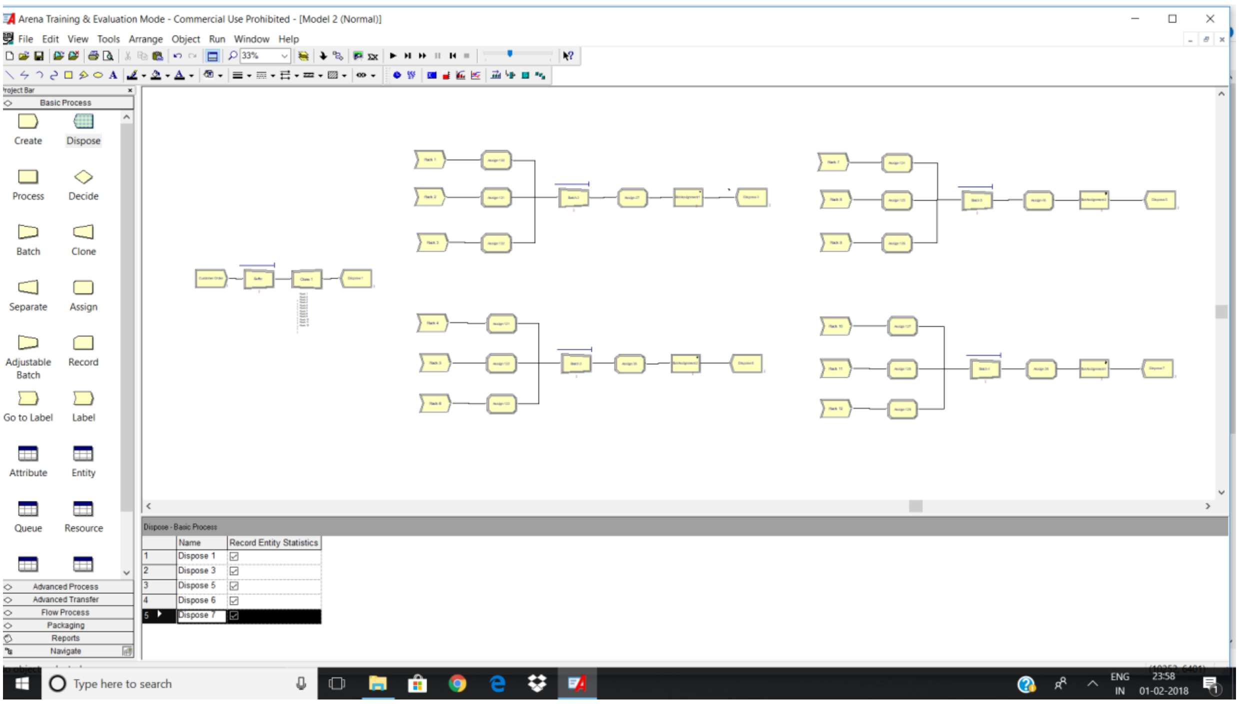
Each BOT is assigned an area in the warehouse and products in that area are assigned to that BOT to deliver.

Bot	Number of Products
BOT 1	22
BOT 2	49
BOT 3	13
BOT 4	16

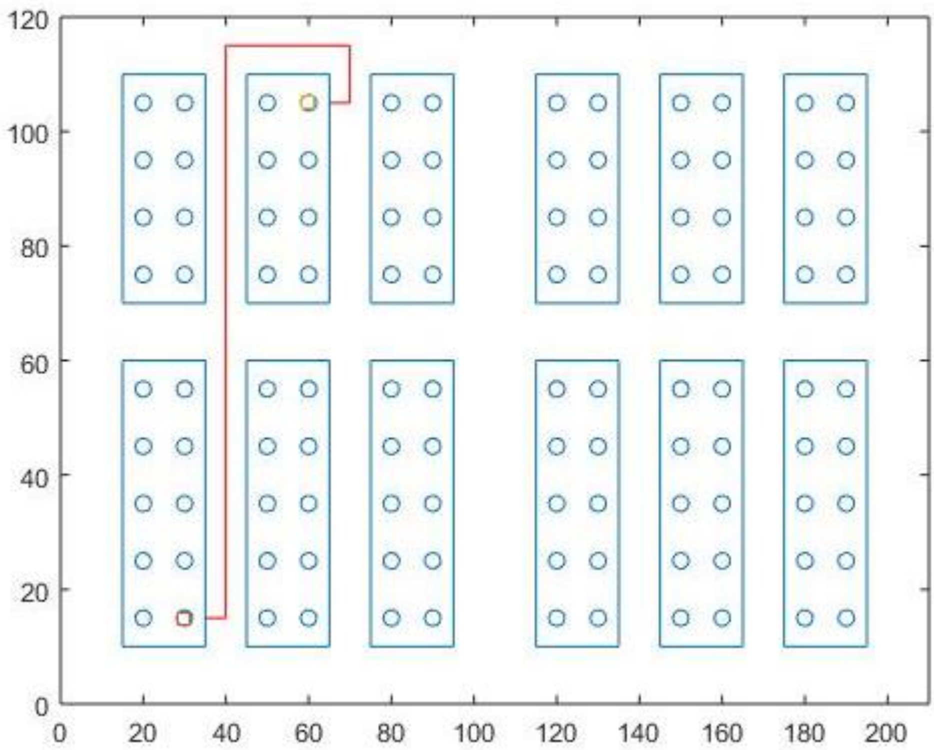
The division of the task between the BOTs

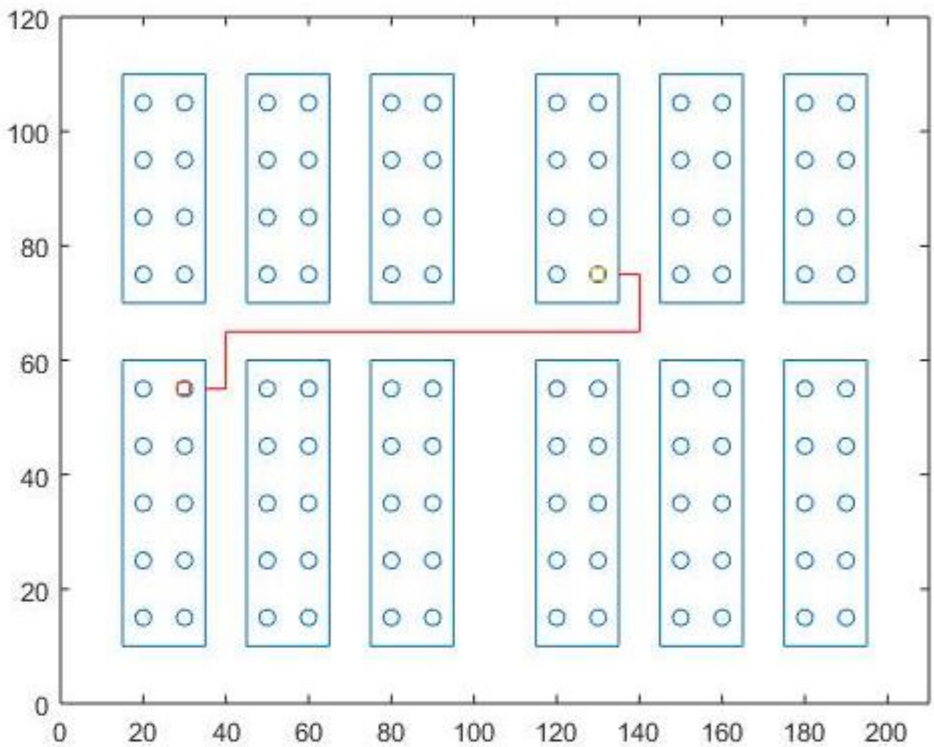


<u>This Job Scheduling Scenario is simulated on Arena Simulation Software</u>

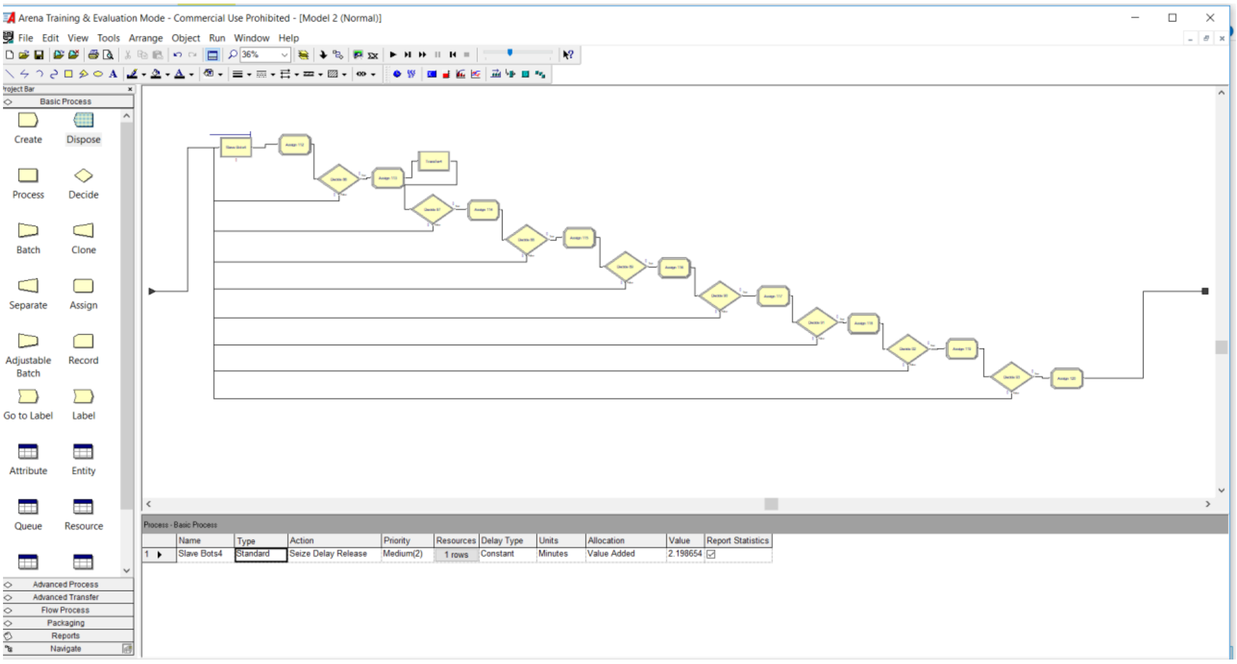


The distances between each product are found using a shortest path algorithm and fed to arena as an excel sheet.





The case of Slave Bot Rotation is also taken into account in the submodule of the system.



<u>The Simulation on Arena Software gives the total delivery time for each BOT</u>

BOT 1

00:00:22 **Entities** February 2, 2018

Unnamed Project

Replications: 1

Replication 1

Start Time: 0.00 Stop Time: 1060.66 Time Units: Minutes

Bot 1

Time	Average	Half Width	Minimum	Maximum
Other Time	0.00	(Insufficient)	0.00	0.00
Wait Time	0.00	(Insufficient)	0.00	0.00
VA Time	13.8429	(Insufficient)	12.5138	15.0731
NVA Time	0.00	(Insufficient)	0.00	0.00
Total Time	25.6198	(Insufficient)	23.2717	27.5681
Transfer Time	11.7768	(Insufficient)	10.6133	13.2536

Other	Value			
Number In	10			
WIP	0.2415	(Insufficient)	0.00	1.0000
Number Out	10			

BOT 2

00:00:22 **Entities** February 2, 2018

Unnamed Project

Replications: 1

Replication 1

Start Time : 0.00 Stop Time : 1060.66 Time Units : Minutes

Bot 2

Time	Average	Half Width	Minimum	Maximum
Transfer Time	16.8220	(Insufficient)	15.6809	18.3147
VA Time	32.2635	(Insufficient)	29.9086	34.4264
Total Time	49.0855	(Insufficient)	45.7109	50.9871
Other Time	0.00	(Insufficient)	0.00	0.00
NVA Time	0.00	(Insufficient)	0.00	0.00
Wait Time	0.00	(Insufficient)	0.00	0.00

Other	Average	Half Width	Minimum	Maximum
WIP	0.4628	(Insufficient)	0.00	1.0000
Number In	10			

BOT 3

00:00:22 **Entities** February 2, 2018

Unnamed Project

Replications: 1

Replication 1

Start Time : 0.00 Stop Time : 1060.66 Time Units : Minutes

Bot 3

Time	Average	Half Width	Minimum	Maximum
Wait Time	0.00	(Insufficient)	0.00	0.00
Transfer Time	3.0553	(Insufficient)	0.5530	5.7559
Other Time	0.00	(Insufficient)	0.00	0.00
VA Time	11.4934	(Insufficient)	7.7616	18.2040
Total Time	14.5487	(Insufficient)	9.5535	23.4525
NVA Time	0.00	(Insufficient)	0.00	0.00

Other	Average	Half Width	Minimum	Maximum
WIP	0.1372	(Insufficient)	0.00	1.0000
Number In	10			
Number Out	10			

BOT 4

00:00:22 **Entities** February 2, 2018

Unnamed Project Replications: 1

Replication 1 Start Time: 0.00 Stop Time: 1060.66 Time Units: Minutes

Bot 4

Time	Average	Half Width	Minimum	Maximum
NVA Time	0.00	(Insufficient)	0.00	0.00
Wait Time	0.00	(Insufficient)	0.00	0.00
Other Time	0.00	(Insufficient)	0.00	0.00
VA Time	6.3761	(Insufficient)	2.1987	8.7946
Total Time	10.8940	(Insufficient)	3.7565	15.0262
Transfer Time	4.5179	(Insufficient)	1.5579	6.2316

Other	Average	Half Width	Minimum	Maximum
WIP	0.1027	(Insufficient)	0.00	1.0000
Number In	10			
Number Out	10			

The Time for Delivery of Order for each BOT are

Bot	**Delivery Time (approx.)**
BOT 1	27.5 mins
BOT 2	51 mins
BOT 3	23.5 mins
BOT 4	15 mins

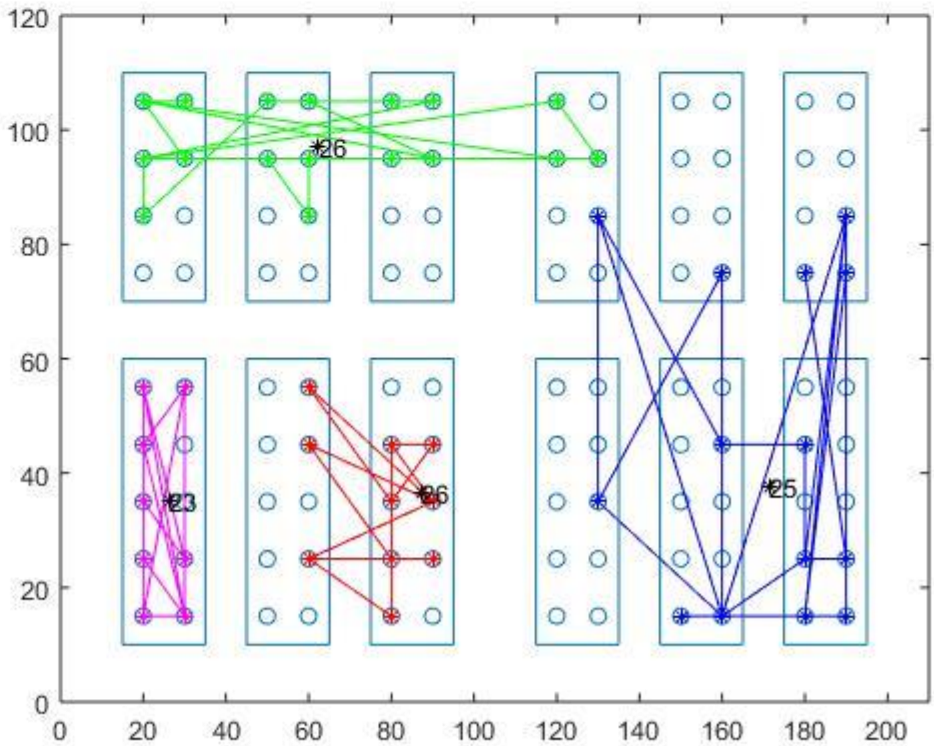
Hence as seen here the Job Scheduling is not Optimized as BOT 2 takes 51 mins and all other bots are done collecting orders in 27.5 mins and remain idle for the rest of the time.

Optimized Warehousing

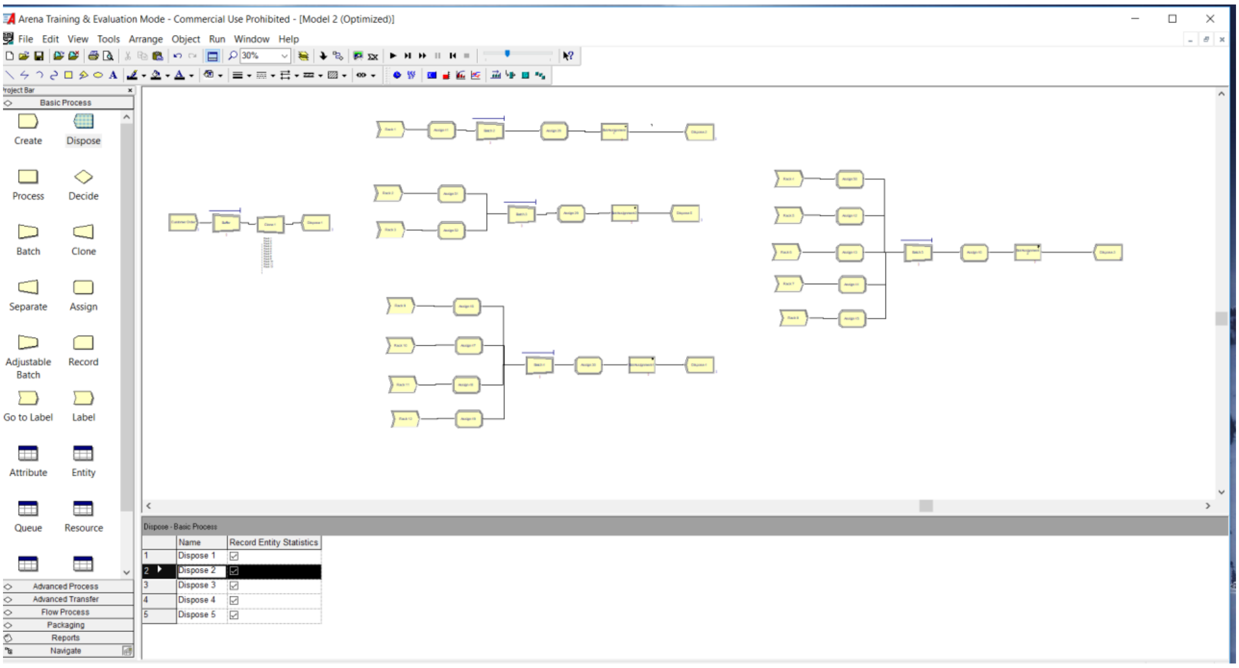
Each BOT is assigned an area in the warehouse and products in that area are assigned to that BOT to deliver.

Bot	**Number of Products**
BOT 1	23
BOT 2	26
BOT 3	25
BOT 4	26

The division of the task between the BOTs



<u>This Job Scheduling Scenario is simulated on Arena Simulation Software</u>



<u>The Simulation on Arena Software gives the total waiting time for each BOT</u>

BOT 1

23:38:34 **Entities** February 1, 2018

Unnamed Project

Replications: 1

Replication 1

Start Time : 0.00 Stop Time : 1130.51 Time Units : Minutes

Bot 1

Time	Average	Half Width	Minimum	Maximum
VA Time	13.5202	(Insufficient)	11.6206	15.0653
Total Time	25.4578	(Insufficient)	23.2580	26.9809
NVA Time	0.00	(Insufficient)	0.00	0.00
Transfer Time	11.9376	(Insufficient)	11.0796	12.8984
Wait Time	0.00	(Insufficient)	0.00	0.00
Other Time	0.00	(Insufficient)	0.00	0.00

Other	Value			
Number Out	10			
WIP	0.2252	(Insufficient)	0.00	1.0000
Number In	10			

BOT 2

23:48:48 **Entities** February 1, 2018

Unnamed Project

Replications: 1

Replication 1 Start Time: 0.00 Stop Time: 1130.51 Time Units: Minutes

Bot 2

Time	Average	Half Width	Minimum	Maximum
Transfer Time	14.0783	(Insufficient)	12.9813	15.3376
Wait Time	0.00	(Insufficient)	0.00	0.00
Other Time	0.00	(Insufficient)	0.00	0.00
Total Time	25.4225	(Insufficient)	23.2580	28.2187
NVA Time	0.00	(Insufficient)	0.00	0.00
VA Time	11.3442	(Insufficient)	9.5893	14.4887

Other	Value
Number In	10
Number Out	10

BOT 3

23:48:48 **Entities** February 1, 2018

Unnamed Project

Replications: 1

Replication 1 Start Time: 0.00 Stop Time: 1130.51 Time Units: Minutes

Bot 3

Time	Average	Half Width	Minimum	Maximum
NVA Time	0.00	(Insufficient)	0.00	0.00
Other Time	0.00	(Insufficient)	0.00	0.00
Wait Time	0.00	(Insufficient)	0.00	0.00
Transfer Time	18.2222	(Insufficient)	16.5957	19.0805
Total Time	30.9031	(Insufficient)	27.3806	33.1756
VA Time	12.6809	(Insufficient)	10.7849	14.4186

Other	Average	Half Width	Minimum	Maximum
WIP	0.2734	(Insufficient)	0.00	1.0000
Number Out	10			
Number In	10			

BOT 4

23:48:48 **Entities** February 1, 2018

Unnamed Project Replications: 1

Replication 1 Start Time : 0.00 Stop Time : 1130.51 Time Units : Minutes

Bot 4

Time	Average	Half Width	Minimum	Maximum
Wait Time	0.00	(Insufficient)	0.00	0.00
NVA Time	0.00	(Insufficient)	0.00	0.00
VA Time	12.4096	(Insufficient)	8.8640	13.2960
Other Time	0.00	(Insufficient)	0.00	0.00
Total Time	26.2907	(Insufficient)	18.7791	28.1686
Transfer Time	13.8812	(Insufficient)	9.9151	14.8727

Other	Value			
Number Out	10			
Number In	10			
WIP	0.2326	(Insufficient)	0.00	1.0000

The Time for Delivery of Order for each BOT are

Bot	**Delivery Time (approx.)**
BOT 1	27 mins
BOT 2	28 mins
BOT 3	33 mins
BOT 4	28 mins

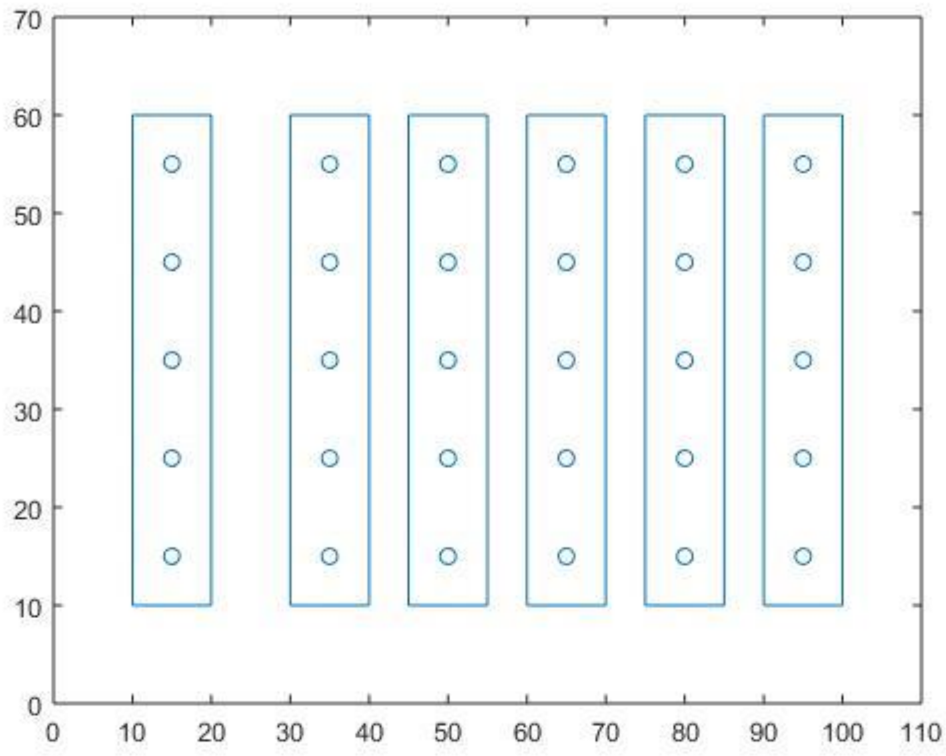
As seen in this case the BOTs take similar time to finish their jobs and the idle time is close to zero.

The algorithm optimizes the delivery of an order of 100 products by approx. 18 minutes.

Case 2:

Scenario: A warehouse with 30 products shelved in 6 one sided shelves.

Environment



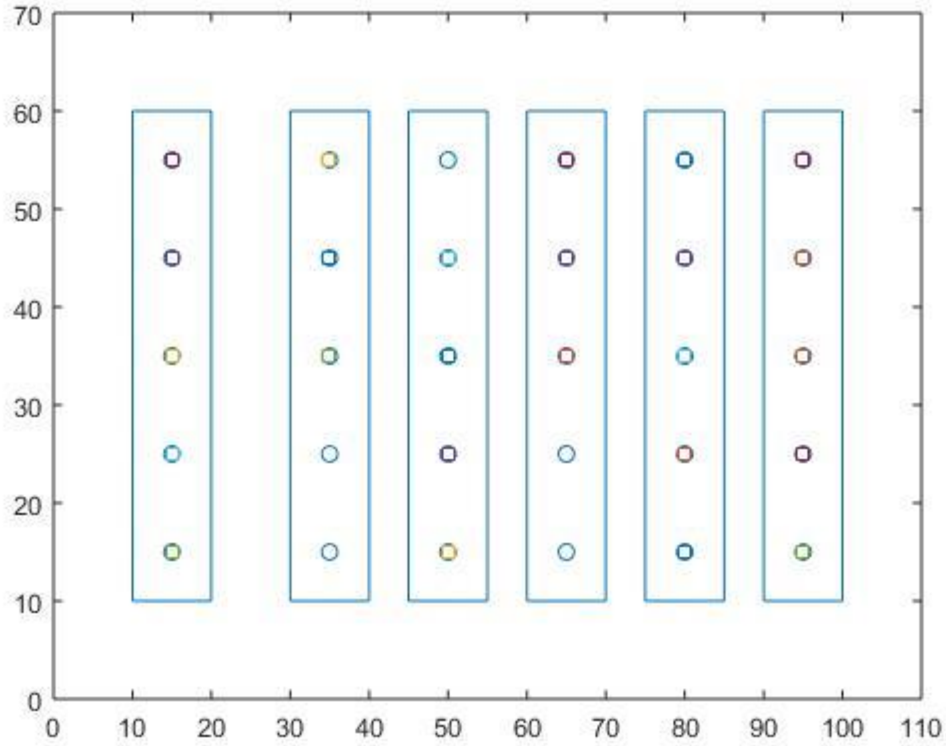
Environment Details

Number of Bots: 3 (Master bots)

Simulation: An order of 50 products

- An order of 50 products was randomly generated
- 3 bots to pick up the products for the order
- 6 shelves with a total of 30 products

An Order of 50 products

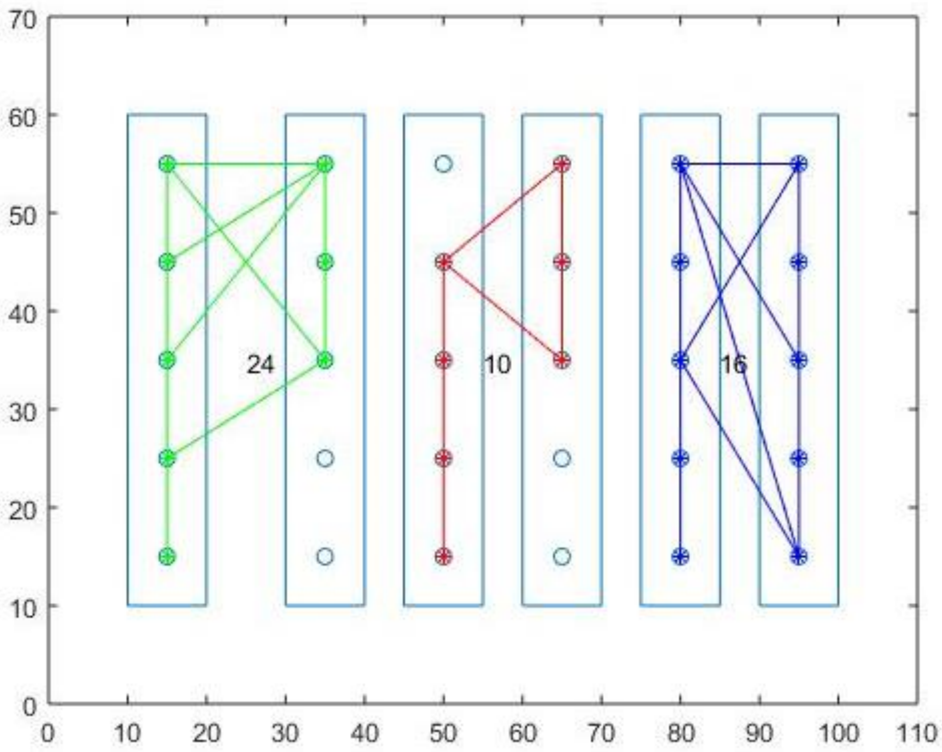


Traditional Warehousing

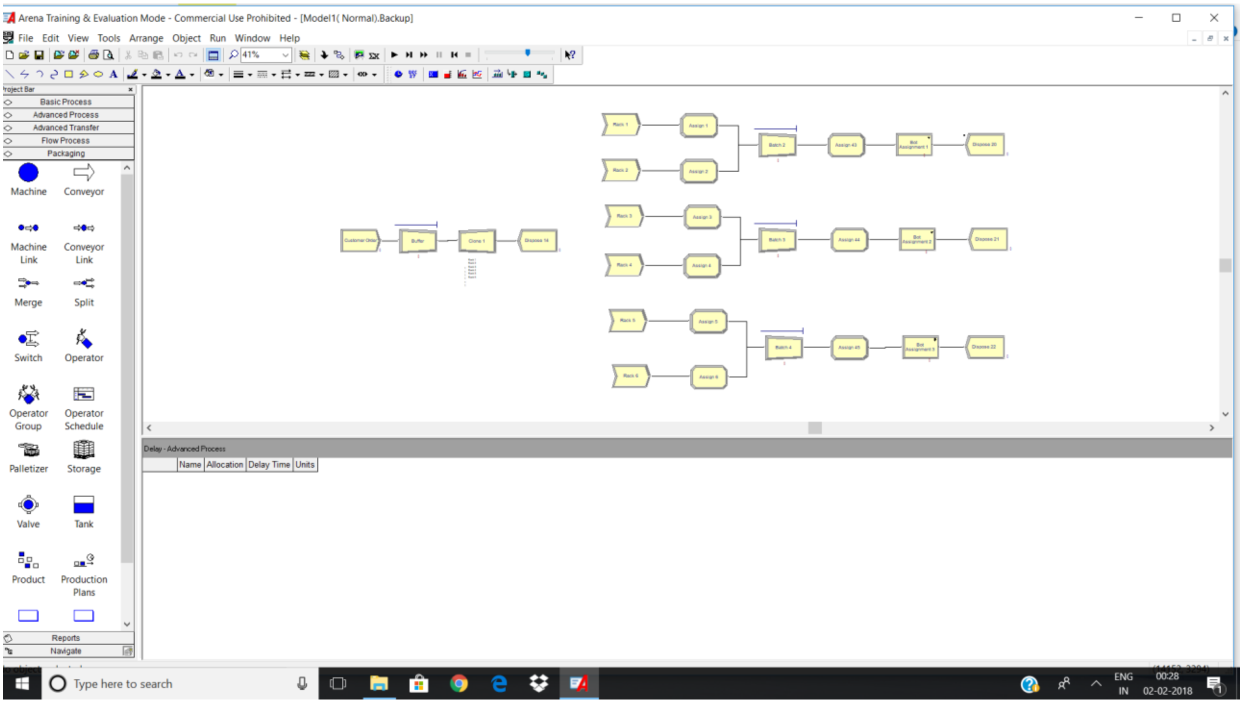
Each BOT is assigned an area in the warehouse and products in that area are assigned to that BOT to deliver.

Bot	Number of Products
BOT 1	24
BOT 2	10
BOT 3	16

The division of the task between the BOTs



<u>This Job Scheduling Scenario is simulated on Arena Simulation Software</u>



The Simulation on Arena Software gives the total delivery time for each BOT

BOT 1

00:29:24 **Entities** February 2, 2018

Unnamed Project Replications: 1

Replication 1 Start Time: 0.00 Stop Time: 1003.14 Time Units: Minutes

Bot 1

Time	Average	Half Width	Minimum	Maximum
Other Time	0.00	(Insufficient)	0.00	0.00
Wait Time	0.00	(Insufficient)	0.00	0.00
Total Time	17.4222	(Insufficient)	10.8889	21.7777
NVA Time	0.00	(Insufficient)	0.00	0.00
VA Time	9.2369	(Insufficient)	5.7731	11.5462
Transfer Time	8.1852	(Insufficient)	5.1158	10.2316

Other	Value
Number Out	10
Number In	10

BOT 2

00:29:24 **Entities** February 2, 2018

Unnamed Project Replications: 1

Replication 1 Start Time: 0.00 Stop Time: 1003.14 Time Units: Minutes

Bot 2

Time	Average	Half Width	Minimum	Maximum
VA Time	3.2265	(Insufficient)	1.8979	4.7448
NVA Time	0.00	(Insufficient)	0.00	0.00
Other Time	0.00	(Insufficient)	0.00	0.00
Wait Time	0.00	(Insufficient)	0.00	0.00
Transfer Time	3.1024	(Insufficient)	1.8250	4.5624
Total Time	6.3289	(Insufficient)	3.7229	9.3072

Other	Average	Half Width	Minimum	Maximum
WIP	0.06309139	(Insufficient)	0.00	1.0000

BOT 3

00:29:24 **Entities** February 2, 2018

Unnamed Project Replications: 1

Replication 1 Start Time : 0.00 Stop Time : 1003.14 Time Units : Minutes

Bot 3

Time	Average	Half Width	Minimum	Maximum
Transfer Time	4.5349	(Insufficient)	3.8871	6.4785
Total Time	8.7393	(Insufficient)	7.4908	12.4847
NVA Time	0.00	(Insufficient)	0.00	0.00
VA Time	4.2044	(Insufficient)	3.6037	6.0062
Wait Time	0.00	(Insufficient)	0.00	0.00
Other Time	0.00	(Insufficient)	0.00	0.00

Other	Value			
Number Out	10			
Number In	10			
WIP	0.08711994	(Insufficient)	0.00	1.0000

The Time for Delivery of Order for each BOT are

Bot	**Delivery Time (approx.)**
BOT 1	22 mins
BOT 2	9 mins
BOT 3	12.5 mins

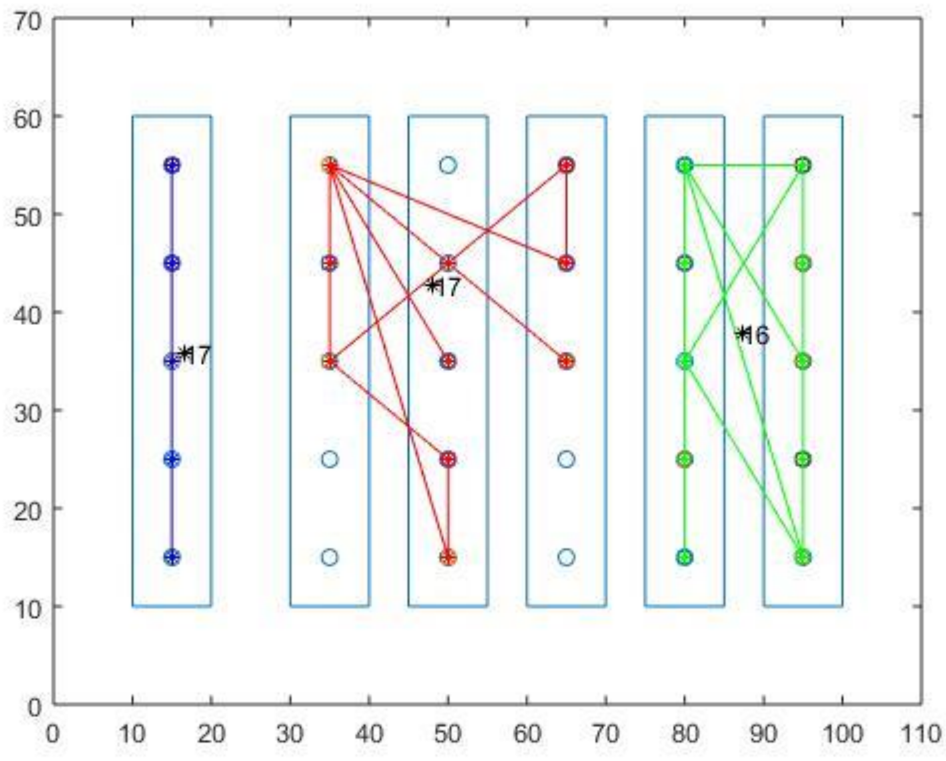
Hence as seen here the Job Scheduling is not Optimized as BOT 2 takes 51 mins and all other bots are done collecting orders in 27.5 mins and remain idle for the rest of the time.

Optimized Warehousing

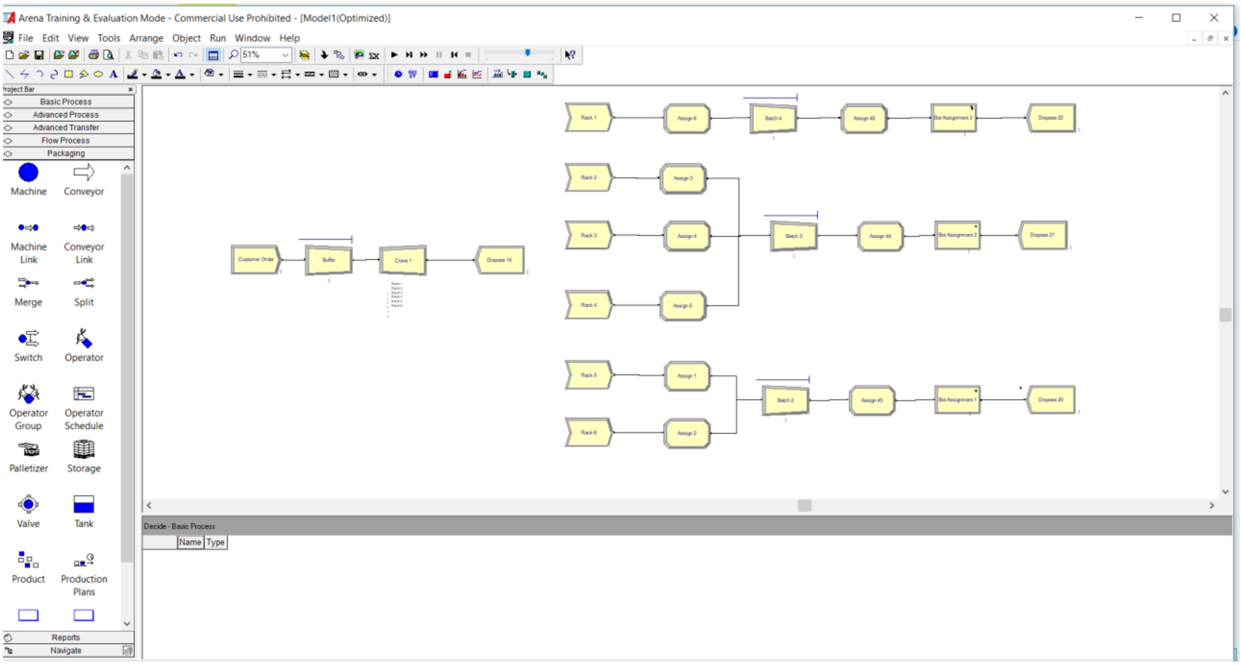
Each BOT is assigned an area in the warehouse and products in that area are assigned to that BOT to deliver.

Bot	Number of Products
BOT 1	17
BOT 2	17
BOT 3	16

The division of the task between the BOTs



This Job Scheduling Scenario is simulated on Arena Simulation Software



The Simulation on Arena Software gives the total waiting time for each BOT

BOT 1

00:45:20 **Entities** February 2, 2018

Unnamed Project Replications: 1

Replication 1 Start Time: 0.00 Stop Time: 1005.97 Time Units: Minutes

Bot 1

Time	Average	Half Width	Minimum	Maximum
VA Time	4.3520	(Insufficient)	2.7200	5.4400
Other Time	0.00	(Insufficient)	0.00	0.00
Wait Time	0.00	(Insufficient)	0.00	0.00
NVA Time	0.00	(Insufficient)	0.00	0.00
Transfer Time	4.3343	(Insufficient)	2.7089	5.4179
Total Time	8.6863	(Insufficient)	5.4289	10.8579

Other	Average	Half Width	Minimum	Maximum
WIP	0.08634791	(Insufficient)	0.00	1.0000
Number Out	10			
Number In	10			

BOT 2

00:45:20 **Entities** February 2, 2018

Unnamed Project Replications: 1

Replication 1 Start Time: 0.00 Stop Time: 1005.97 Time Units: Minutes

Bot 2

Time	Average	Half Width	Minimum	Maximum
NVA Time	0.00	(Insufficient)	0.00	0.00
Other Time	0.00	(Insufficient)	0.00	0.00
Total Time	8.5061	(Insufficient)	5.4878	13.7195
Wait Time	0.00	(Insufficient)	0.00	0.00
Transfer Time	4.8791	(Insufficient)	3.1478	7.8695
VA Time	3.6270	(Insufficient)	2.3400	5.8500

Other	Average	Half Width	Minimum	Maximum
WIP	0.08455646	(Insufficient)	0.00	1.0000
Number In	10			

BOT 3

00:45:20 **Entities** February 2, 2018

Unnamed Project Replications: 1

Replication 1 Start Time: 0.00 Stop Time: 1005.97 Time Units: Minutes

Bot 3

Time	Average	Half Width	Minimum	Maximum
NVA Time	0.00	(Insufficient)	0.00	0.00
Other Time	0.00	(Insufficient)	0.00	0.00
Wait Time	0.00	(Insufficient)	0.00	0.00
VA Time	4.0842	(Insufficient)	3.6037	6.0062
Transfer Time	4.4054	(Insufficient)	3.8871	6.4785
Total Time	8.4896	(Insufficient)	7.4908	12.4847

Other	Value			
Number Out	10			
Number In	10			
WIP	0.08439266	(Insufficient)	0.00	1.0000

The Time for Delivery of Order for each BOT are

Bot	Delivery Time (approx.)
BOT 1	11 mins
BOT 2	14 mins
BOT 3	12.5 mins

As seen in this case the BOTs take similar time to finish their jobs and the idle time is close to zero.

The algorithm optimizes the delivery of an order of 50 products by approx. 8 minutes.

The results of both the cases show that the optimized solution for warehousing saves time of delivery of the order and reduces the idle time of the bots.

RESULTS

Case	Number of Products in Order	Time Saved by Optimization
1	100	18 mins
2	50	8 mins

Hence our proposed algorithm optimizes the current warehousing solution in a very effective manner.