Strategic and operational plan for better material handling

By

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B.Eng, Mechanical Engineering

Tongji University, China, 2007

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING IN MANUFACTURING

AT THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

SEPTEMBER 2008

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Submitted to the Department of Mechanical Engineering on August 19, 2008
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ABSTRACT

Currently the material handling in NPC Singapore is done manually via forklift trucks. As the production volume increases and a new product launches, the current capacity will not be sufficient for 2012. In order to avoid the production loss and increase the operational efficiency, four solutions have been tested, including forklift trucks and labor extension, Kanban redesign in staging areas, conveyor implementation in staging areas and automating the transportation between the warehouse and production via implementing AGVs or transfer cars. In this thesis research we specifically analyze the use of AGVs and transfer cars. By implementing two transfer cars in 2012, the system capacity will remain adequate until 2018. This investment provides a $364,165 net present value and a 29% internal rate of return.

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Acknowledgement

First and foremost, I would like to express my deepest appreciation to our thesis supervisor, Professor Stephen C. Graves, from Sloan School of Management in MIT, for his consistent guidance and encouragement throughout the project. I am grateful and inspired by his patience, dedication to excellence, and careful attention to this project.

I would like to thank NPC Singapore for providing us this great opportunity. I gratefully acknowledge the help of the stuff in NPC Singapore for their kind support during my attachment in the company. I would especially like to express my gratitude to the manufacturing lead and the warehouse lead for supporting and guiding me throughout the project. Thanks to the technical service lead for sponsoring this project. Also thanks to LSS engineer, supply chain planner and finance analyst for taking time off their busy schedules to give me guidance in this project and patiently answering all my enquiries.

Kind thanks also go to Ms. Jennifer Lynn Craig for providing us patient guidance on writing our thesis and giving us valuable feedback and suggestions. I am grateful to the people involved in this project especially Dr. Brian W. Anthony, Professor David E. Hardt, and Professor Stanley B Gershwin.

Finally, I would like to thank my teammate, my friend, Mr. Yizhe Cen. This project could not be possible without his teamwork. Also thanks to my other friends from the Singapore MIT Alliance program for their consistent support and encouragement.

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1. Introduction

NPC Pharmaceuticals is a global research-driven pharmaceutical company, which has over 50 international sites. This thesis is the result of a seven month project at NPC, Singapore. This project focuses on the material handling problem in the pharmaceutical formulation plant which includes the warehouse and pharmaceutical facilities.

1.1 Background

Material handling is one of the key parts of the whole operational system in manufacturing areas. Currently the material handling in NPC Singapore is done manually via forklift trucks. As the production volume increases and a new product launches, the current capacity will not be sufficient in the future. Using automatic or semi-automatic technology that automates the transportation and solves material handling problems could be more efficient than the manual method. So automating the transportation as one approach to achieve better material handling will be tested via ROI (Return on Investment) analysis. Besides automating the transportation, automating the staging areas for material storage will be tested too as another solution. This thesis focuses on delivering the result of our material handling project to improve the efficiency and effectiveness of the material handling system at NPC, Singapore.

1.2 Manufacture Facilities and Material Flows

This project considers the pallet movements along the spine, which is a corridor that connects the warehouse and three pharmacutical facilities: PF1, PF2 and currently under construction PF3. The reason why we focus on the pallet movements along the spine is because the large number of movements are happening along the spine and its geographic position is very critical.

The warehouse currently serves for storing the finished goods and raw materials, both of which are placed on top of standard pallets. Currently there are around 3,500 pallets space in warehouse. Each pallet of raw materials or finished goods is stored at a certain rack place. There are 15 rows of racks in total. Each rack has five levels. Each level is around 1.6 meters high. Generally two pallets of materials will be stacked in one rack place. At every rack place there is a barcode, which is used as a representation of the data, including the location, name and quantity of the materials. Each pharmaceutical facility has two major material staging areas: Stage In, for raw material storage; Stage Out, for finished goods storage; plus a waste staging area, for waste storage. The floor plan is indicated in Figure 1. The identification code for PF1 staging areas is 02, namely 02 Stage In and 02 Stage Out. The code for PF2 staging areas is 03, namely 03 Stage In and 03 Stage Out. Each staging area has a Kanban Layout, the material sent and received are based on the Kanban rule. Kanban is basically a signboard. For NPC Singapore, the Kanban Layout includes the name and pallet space arrangement for each raw material or finished goods. According to the Kanban control rule, if some certain pallet space for the raw materials are empty, this means those raw materials are required to be fulfilled for production.

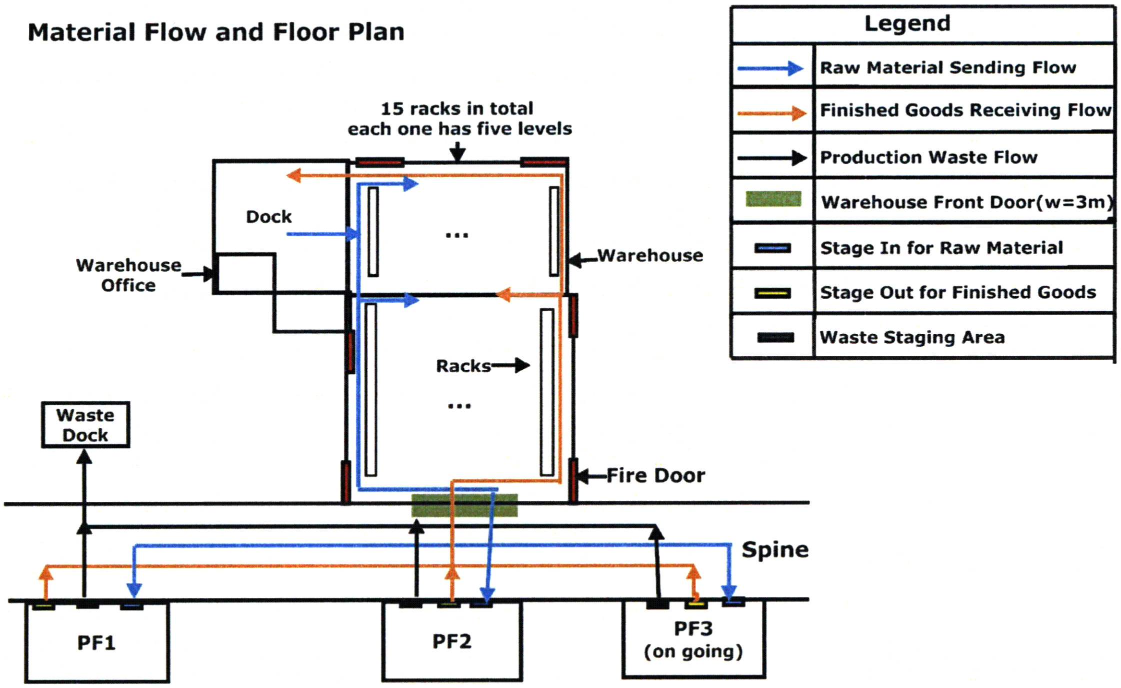


Figure 1 Material flow and floor plan

As we can notice from Figure 1, there are material flows including raw material sent from the warehouse to Stage In areas and finished goods received from Stage Out areas to the warehouse. In addition, there will be a small portion of reverse-direction flows. For instance, raw materials are sent back to the warehouse from Stage In areas due to change of product campaign, and finished goods are moved from warehouse back to Stage Out area for re-inspection or packaging. Additionally, other than the production material flows as mentioned before, there will be two other flows involved as well: firstly, human flow from warehouse office to pharmaceutical facilities; secondly, waste flow from waste staging area to waste dock. So to sum up, the material flows along the spine could be characterized as shown in Figure 1.

1.3 Products

The products produced by NPC Singapore now can be categorized into two: Product A and Product B. In addition, a Product C is expected to be manufactured soon_will be launched by the end of 2009. There are four production steps for the products: charging, granulation, blending, and compression. For Product B, the first three production steps are performed in PF1, after which the Product B WIPs (Work in Process) are transported from PF1 to PF2 along the spine in order to finish the last manufacturing step. For Product A, all the manufacturing steps are performed in PF1.

1.4 Organization of the Thesis

This thesis study is the result of a team project with Mr. Yizhe Cen. His thesis study—"Improve the Efficiency and Effectiveness of Material Handling for a Pharmaceutical Factory" focuses on the solutions in the staging areas. This thesis focuses on examining the automation of the transportation between the warehouse and the staging areas. Chapter 1 gave an overall introduction of the company and the project. Chapter 2 will describe the problem and state the objective of this project. Chapter 3 will document the previous work people have done on improving the efficiency of material handling via automation implementation. Chapter 4 will present the details of the methodology to solve the problem. Chapter 5 will focus on the detailed discussion about the solutions to the problem. Chapter 6 will conclude with recommendations and suggestions for future work.

2. Problem Statement

2.1 Product Structure

The whole operational and planning process of material handling revolves around the products that NPC Singapore manufactures. As the product volumes grow and the new product launches, the throughput rate will increase rapidly. So the current man power and transport model might not be sufficient. Therefore, to better understand material movements, studying the complete product structure is critical.

Product A is completely produced by PF1. Compared to Product B, Product A is relatively mature. Since the production requirement for Product A is larger than Product B, the production for Product A runs seven days a week, 24 hours per day whereas Product B is currently manufactured on a five-day week basis.

The finished goods of Product A can be classified into two types: the first one is Product A- 7 and the second one is Product A-9. The raw materials used to manufacture these two products are identical, except for the quantities; the quantity of materials required for Product A-9 is 9/7 times higher than that for Product A-7.

Product B is manufactured across PF1 and PF2 along with a product similar to Product B, called Product B2. Therefore these two will be assumed to be equivalent.~~,~~

2.2 Material Flows

This project involves the material handling process between the warehouse and the pharmaceutical facilities, and hence it would be appropriate to understand the logistics of the material handling process for each product.

In general, when the warehouse receives raw materials from suppliers, the warehouse personnel first store these raw materials in the dock area for inspection. And then raw materials are sent to the open rack places in the warehouse and will wait for the requirement from production side. Stage In areas are used to store raw materials for production. They are the linkage between the warehouse and production, and serve as buffers. And the warehouse personnel bring raw material to the Stage In areas based on Kanban rule. Currently, the raw material for both Product A and Product B are stored in 02 Stage In. The 03 Stage In is used for storing the packaging material for Product B. The process is indicated in the orange flow lines as shown in Figure 1.

Similarly the Stage Out areas are also the linkage between production and the warehouse. And they are used to store the finished goods upon completion of production. Generally warehouse personnel will go to the Stage Out areas and check the availability of finished goods three times per day, depending on the production volume. Whenever there are finished goods, they will pick up the finished goods and send them to the open places in the warehouse to store until there are orders from customers. Once the finished goods are ordered, they will be sent to the dock areas first for inspection and then to ship out. Currently, the finished goods of Product A are stored in 02 Stage Out. The 03 Stage Out is used to store the finished Goods of Product B. The process is indicated in blue flow lines as shown in Figure 1.

2.3 Movement Breakdown

This project is about material movements, and hence to diagnose the problem, we need to understand the material movement breakdown. The project focuses on the material handling along the spine, and generally the material movements can be divided into two categories: movements along the spine and movements not along the spine. Based on the data from database in NPC Singapore, in 2007, there were 358 working days, and there were 14,278 movements in total. 7,865 movements were along the spine, and the other 6,412 movements were not along the spine. The breakdown can be shown by the pie chart in Figure 2.

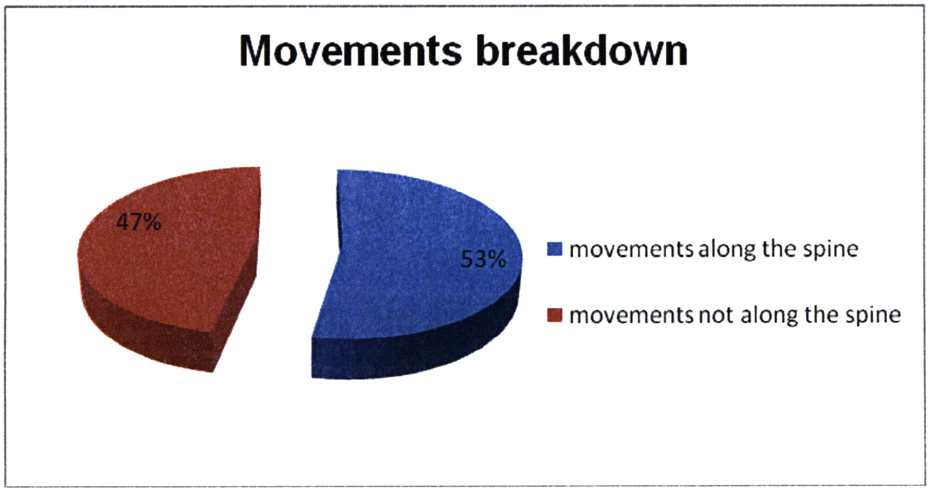


Figure 2 Movements breakdown in 2007

The 53% number of movements along the spine contains four parts: raw material moved from the warehouse to Stage In for production, finished goods moved from Stage Out to the warehouse for shipment, raw material moved from Stage In back to the warehouse due to change of product campaign, and finished goods moved from the warehouse to Stage Out area due to packaging or re-inspection. The distribution of these four parts is described in Figure 3.

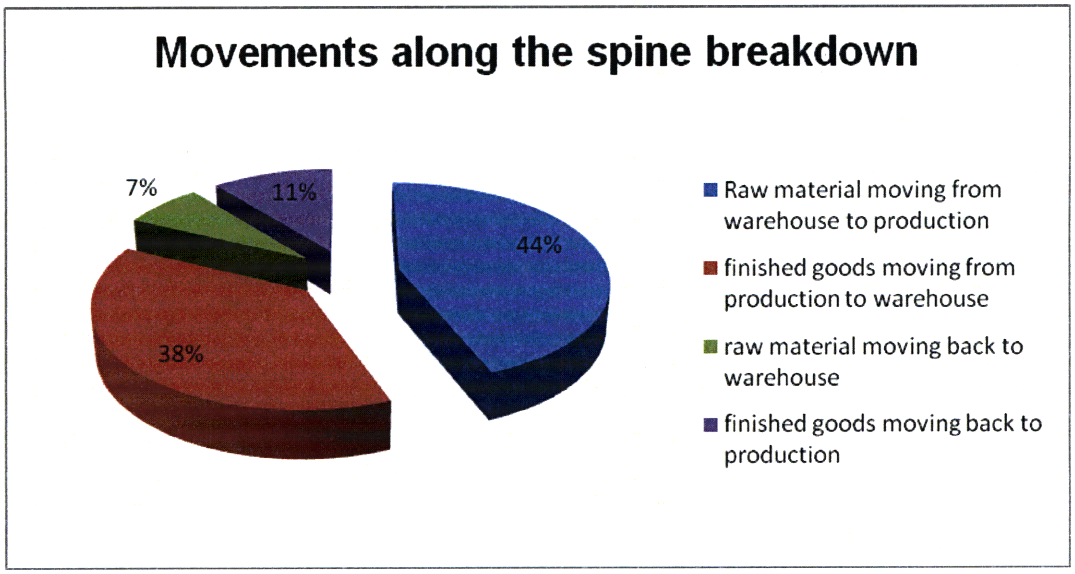


Figure 3 Movements along the spine breakdown

Since there were 358 working days in 2007, the average number of movements along the spine per day based on the 2007 data was 22. But the movements varied a lot from day to day, because the number of movements depends on the production volume. The data details are shown in the run chart in Figure 4. With the daily number of movements, we plot the distribution of the daily movements, as shown in Figure 5. The x axis means the number of daily movements along the spine, and the y axis means the probability of the number of movements.

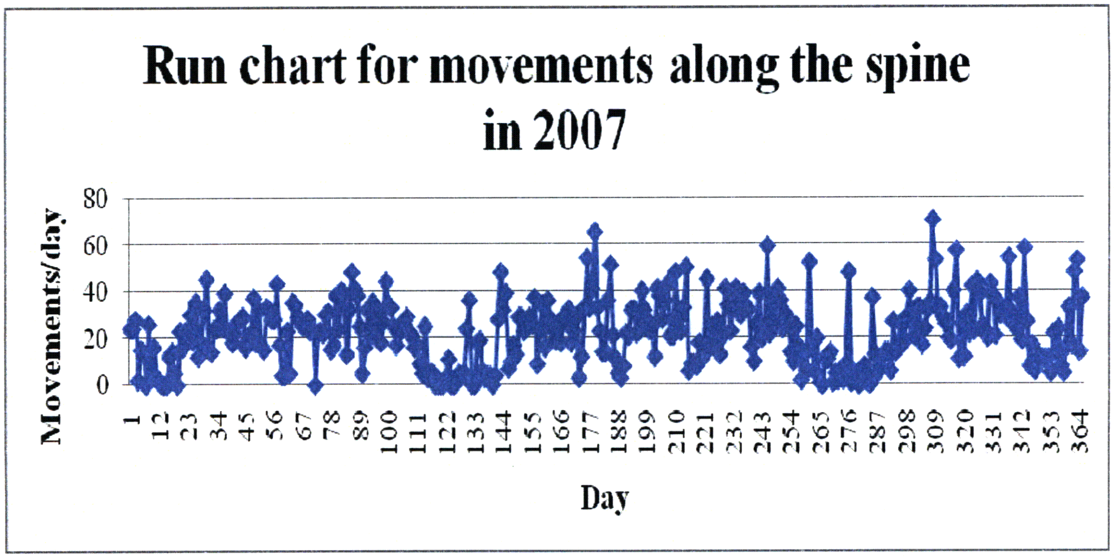


Figure 4 Run chart of daily movements along the spine in 2007

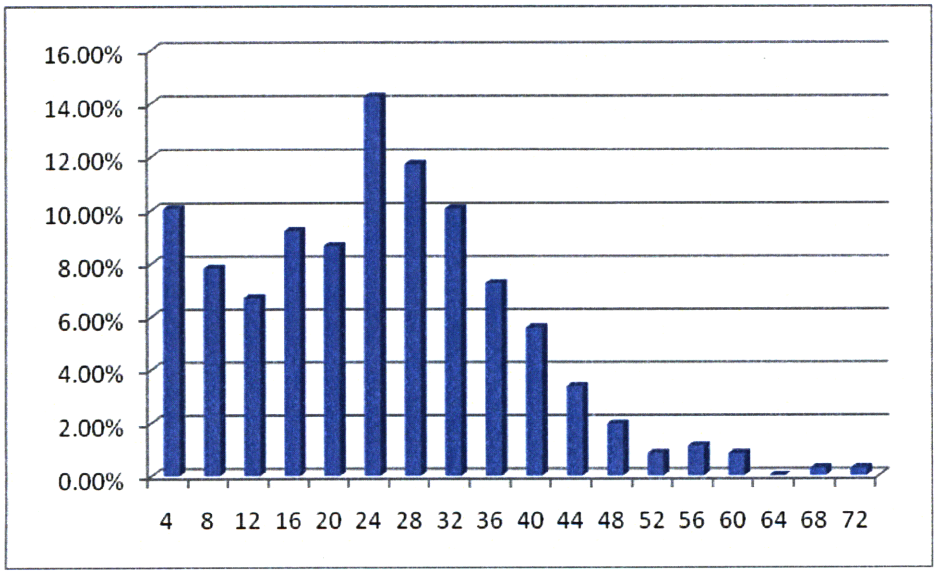


Figure 5 Movements along the spine daily variation

In Figure 5 we notice that the distribution looks like a combination of an exponential distribution and a normal distribution.

The movements not along the spine can be divided into two parts: material receiving and shipping between the warehouse and the dock area, and movements within the warehouse due to space arrangement. The distribution of these two parts is shown in Figure 6.

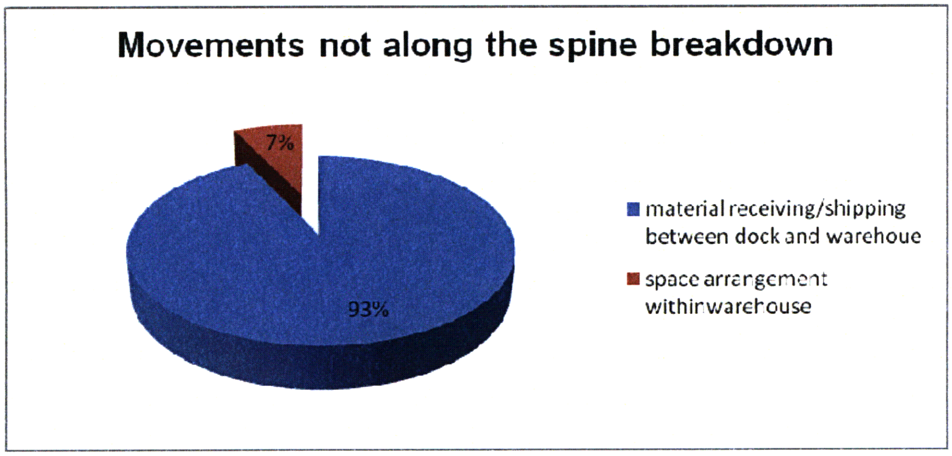


Figure 6 Movements not along the spine breakdown

With 358 working days in 2007, the average daily number of movements not along the spine based was 17.9. Similarly as for movements along the spine, the daily movements not along the spine also varied a lot, depending on the production volume. So the daily movement variation distribution can be plotted, as shown in Figure 7. The x axis means the number of movements not along the spine, and the y axis means the probability.

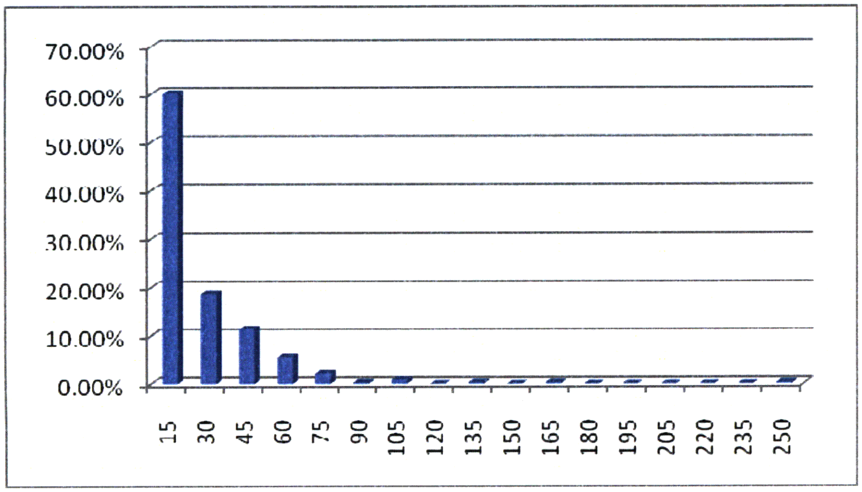


Figure 7 Movements not along the spine daily variation

2.4 Movement Segmentation and Time Taken for Each Segment

In the previous 3 sections in chapter 2, the product structure, material flows, and material movement breakdown were described. As mentioned, there are two major material flows along the spine: raw material moved from the warehouse to production and finished goods moved from production to the warehouse. The primary material flow not along the spine is material receiving and shipping between dock and warehouse. Now we will divide each material flow into segments and determine the time for each segment. From this we will know which material flow consumes more time and which consumes less time, so to determine the drivers of the problems in current material handling system.

For raw material movements, firstly, the warehouse personnel will go from the warehouse office to the Stage Ins to check their availability. Based on the Kanban rule, they will know what kind of raw materials are needed. While the raw materials were received from suppliers and stored in the warehouse, the identical information for each raw material was recorded in the Database. The information includes the name, quantity and location for each raw material and the date that the raw material was stored. Therefore, based on the first in first out (FIFO) rule, the warehouse personnel will create a supplying queue for each required raw material. For example, according to the Kanban in raw material staging area, the warehouse personnel notice the pallet place for RW_A1 is empty, and they will know that RW_A1 is required for production. And then they will go back to the warehouse office and access to the Database to check the inventory of RW_A1 in the warehouse. After that, they will create a queue for supplying RW_A1 based on the FIFO rule, which means the RW_A1 that was stored in the warehouse first has the top priority. The queuing information will be sent to the hand devices. The hand devices are paperless picking devices with wireless capability, which combine the data entry and barcode scanning capabilities. With the queuing information, the warehouse workers can go to the desired raw material storage place, and scan the barcode on the rack by the hand device. After that, that raw material will be taken out of the queuing system. And then the warehouse workers will use a vertical forklift truck to lower the material pallet down, after which that material pallet will be moved via forklift truck from the warehouse to the Stage Ins for production. That is the end of a pallet movement. The segmentation and timing is summarized in Table 1.

Table 1 Segmentation and timing for raw materials moved from warehouse to production

Sequence	Raw material moving from warehouse to Stage In	Time (min)
1	Create queue in Data3	0.08
2	Get access to info from handheld device	4.06
3	Move pallet down from the rack	1.42

4	Travel from WH to staging	1.08
5	Space adjustment in Stage In	4.0
6	Move from staging to Stage In	1.0
	Total time per movement	12.80

From the segments we know that time spent on a raw material movement includes time spent on space adjustment, transportation, interaction with system, and others. This can be described in a pie chart as shown in Figure 8.

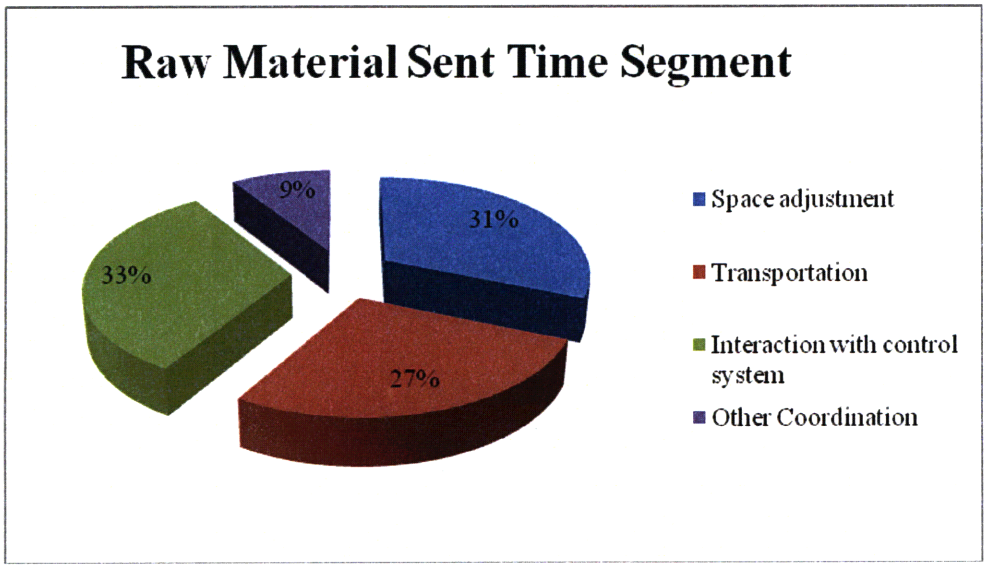


Figure 8 Raw materials moved from warehouse to production time segment

Regarding the timing process, we achieve the time by manual timing with 9 samples. And then we double check the accuracy by comparing these estimates to actual movement times inferred from the Database. For example, in the Database we can find observations in which a pallet of RW_A2 was moved from the warehouse to 02 Stage In at time X by worker M, after which a second pallet of RW_A2 was moved from the warehouse to 02 Stage In by worker M at time Y. Hence, we can infer that the time taken of the movement of the second pallet of RW_A2 is Y-X, as shown in Table 2.

Table 2 Transportation time calculation through database

Item description	From	To	User	Date	Time	Δ
RW_A2	W3H-45D	02IN	TAYCH	4/11/2007	8:37:24	
RW_A2	W3H-47C	02IN	TAYCH	4/11/2007	8:40:55	0:03:31

And this time includes all the transportation time, namely segment 3, 4 and 6. It is 3.5 minutes. We were able to compare nearly 200 such observations from the Database; the mean number is 3.65 minutes. Based on this comparison we are confident that our timing as shown in the table above is accurate and relatively conservative. The total time per movement is the sum of time from segment one to six, multiplied by 110%. We inflate the segment times by 10% extra to amount for the walking time and coordination time per movement.

For finished goods receiving, firstly, warehouse people will go to the warehouse staging area to check the availability of finished goods. If there are finished goods that need to be moved, they will either go back to warehouse to drive the forklift truck to perform the movements or communicate with other warehouse people via radio device to ask them to do the movements. Before moving back directly to the warehouse, all the finished goods need to be moved outside the Stage Out area for checking and strapping, after which they could be moved back to the desired rack place in warehouse. As the warehouse worker scan the barcode on the rack to remember the location to store that pallet of finished goods, a finished goods receiving movement is considered to be over. The segmentation and timing is summarized in Table 3.

Table 3 Segmentation and timing for finished goods moved from production to warehouse

Sequence	Finished goods moving from Stage Out to warehouse	Time (min)
1	Travel from WH to staging	0.25
2	Travel from Staging to Stage Out	0.17
3	Space Adjustment	4.00
4	Move pallets from Stage Out to staging	0.96
5	Perform checking	2.48
6	Perform strapping	0.72
7	Travel from Staging to WH and unload	0.90
8	Scan barcode	0.65
	Total time per movement	11.14

From the segments we knew that time spent per movement includes time spent on space adjustment, transportation, checking and strapping, interaction with system and others. So we can use a pie chart to describe the distribution, as shown in Figure 9.

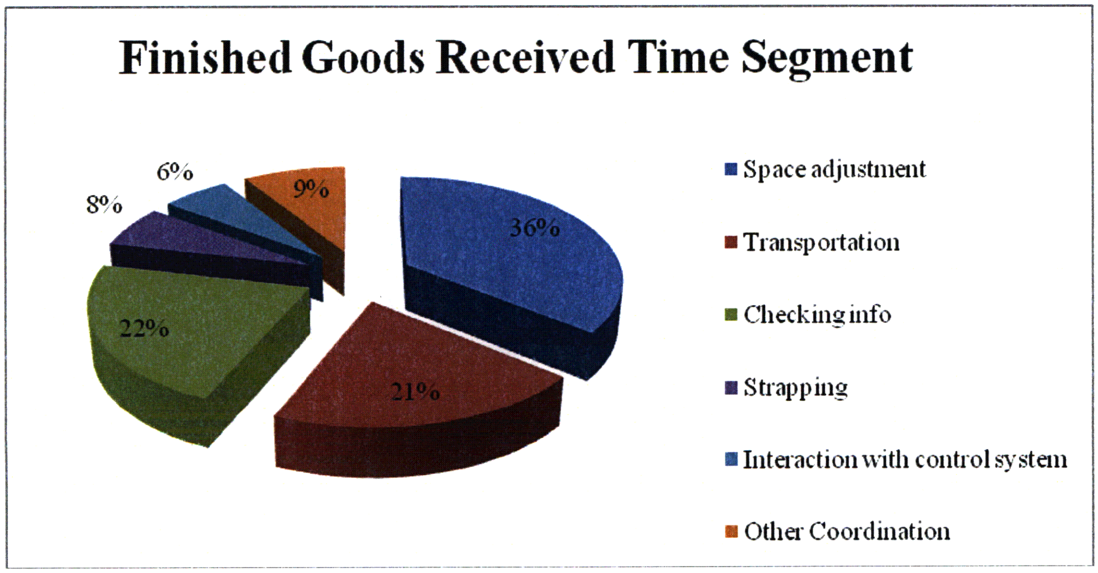


Figure 9 Finished goods moved from production to warehouse time segment

We did the same comparison about the transportation time as for raw material moves. Based on our manual timing, the transportation time including segment 1, 2, 4, 7 is 2.28 minutes. The mean of the data records in the Database is 2.35 minutes. After comparing, we are confident to say that our timing is accurate and relatively conservative. The total time per movement is the sum of time consuming from segment one to eight, multiplied by 110%. The 10% extra is included to account for the walking time and coordination time per movement.

2.5 Current Capacity Calculation and Future Capacity Forecast

2.5.1 Current Capacity Calculation

The current material handling model has been described. In order to validate whether there are efficiency and capacity problems in the current model, we determine the utilization of the warehouse personnel and the forklift trucks. Based on the company concern, we will focus on discussing the capacity utilization along the spine. The utilization is the total time spent on the material movements along the spine per day divided by the total available man hours per day. There are three forklift trucks and three workers dedicated on the material movements along the spine.

There will be three kinds of flows along the spine: the human flow, production flow and waste flow. From section 2.4, we knew the unit time spent on the two kinds of material movements along the spine: 12.8 minutes for raw material moves and 11.14 minutes for finished goods moves. From section 2.2, we knew the average number of movements per day along the spine was 22 in 2007. So from the average number of movements per day and the time spent on the two major flows along the spine, we can get two time figures, which can represent the maximum and minimum time spent on movements along the spine per day. The daily maximum time spent is 4.797 hours and the daily minimum one is 4.175 hours, which makes sense because generally raw material moves takes more time than finished goods moves. In the future calculation, we call the one that uses the minimum value as the best case, and the one that uses the maximum value as the worst case. About the other two flows along the spine, based on the observation and communication with the warehouse people, generally it takes 1 to 1.5 hours per day for them to do the waste movement. And the human flow takes about the same: 1 to 1.5 hours. So the total time spent on activities along the spine can be summarized in Table 4.

Table 4 Time spent on activities along the spine

	Duration(hours)	Duration(hours)
Time Segment	Min	max
Human flow	1	1.5
Production flow	4.078	4.686
Waste flow	1	1.5

Currently, there are two shifts per day in warehouse. Every shift is 8 hours, except for the lunch or dinner time, the effective working hours is around 6.5. At every shift there will be four workers with four forklift trucks. Three of them will be working on the material handling along the spine. So currently the total available man hours on spine activities will be 6.5*2*3=39 hours per day. Therefore, in 2007, the utilization of the current man power and forklift trucks can be summarized in Table 5.

Table 5 Utilization of the current capacity (man power and forklift trucks) in 2007

Duration(best)	2007
Human	1.00
Material	4.08
Waste	1.00
Total	6.18
Utilization=6.18/39	15.6%
Duration(worst)	
Human	1.50
Material	4.69
Waste	1.50
Total	7.80
Utilization=7.8/39	19.7%

2.5.2 Future Capacity Forecast

To calculate the future capacity utilization, we will use the same concept. Firstly, we assume time spent on material flow and waste flow will grow proportionally with the number of movements, while time spent on human flow will remain the same as in base year 2007. This means we need to know the average number of movements along the spine in the future years. Currently we have the long term operational plan (LROP) from the company, which consists of the forecast of the future production quantity in batches. With knowledge of the production volume in batches for each product, now if we know the number of movements along the spine per batch for each product, we will get the total number of movements along the spine.

In order to determine the number of movements per batch, we need to know the number of movements for both finished goods and raw materials per batch for each product. We need to use the Bill of Material (BOM) for each product, which we obtained from the supply chain planner. And then with the data from the base year 2007, we can determine the number of movements along the spine for each kind of raw material, and the finished goods as well. And we knew the actual production quantity in batches in 2007 as well. Thus we can calculate the number of movements per batch. But for some certain kind of raw material, both Product A and Product B use them for production. And we do not know how many movements are for producing Product A and how many movements are for producing Product B from the database. For example, for raw material RW_Comm1, the quantity required for a batch Product A-7 was 21 kg, for Product A-9 was 27kg, for Product B was 24.7kg. The total number of movements along the spine in 2007 was 103, so we estimate for Product A-7 that the number of movements along the spine would be 103*21*479/(21*479+27*339+24.7*23). For Product A-9, we estimate that the number would be 103*27*339/(21*479+27*339+24.7*23), similarly for Product B. With this method, we can obtain the yearly total number of movements along the spine for each raw material. So the number of movements per batch could be calculated. For Product A-7, the information is summarized in Table 6. For Product A-9, the information is summarized in Table 7. For Product B, the information is summarized in Table 8.

Table 6 Number of movements along the spine breakdown for Product A-7

Name	Movements along the spine
Product A-7	1452
RW_A1	3.66
RW_A2	2.09
RW_A3	8.90
RW_A4	449.26

RW_A5	48.17
RW_A6	508.93
RW_A7	260.75
RW_Comm1	52.37
RW_Comm2	108.82
RW_Comm3	44.34
RW_A5	4.71
Number of movements for packaging material	406
Total	3328.78
Number of Movements per batch	7.99

Table 7 Number of movements along the spine breakdown for Product A-9

Name	Movements along the spine
Product A-9	1290
RW_A1	3.33
RW_A2	1.90
RW_A3	8.09
RW_A4	408.75
RW_A5	43.82
RW_A6	463.06
RW_A7	237.24
RW_Comm1	47.66
RW_Comm2	99.02
RW_Comm3	40.34
RW_A5	4.28
Number of movements for packaging material	435
Total	3301.71
Number of Movements per batch	9.73

Table 8 Number of movements along the spine breakdown for Product B

Name	Movements along the spine
Product B	54
RW_B1	92
RW_B2	30
RW_B3	7
RW_Comm1	2.95

RW_Comm2	13.15
RW_B4	21
RW_Comm3	0.31
RW_B5	15
RW_B4	8
RW_B1	31
RW_B6	5
RW_B7	2
Number of movements for packaging material	62
Total	464.24
Number of Movements per batch	20.18

From Table 6, Table 7 and Table 8, we know that number of movements per batch for Product A- 7 was 7.99, for product A-9 was 9.73, for product B was 20.18. Since we do not have the details about Product B2, but we know that its BOM quantities are almost the same, so we assume its movements per batch are the same as Product B. And we assume that Product C has the same number of movements per batch as Product A. We know the production volume forecast in batches. Therefore, with the production volume forecast and the movements per batch for each product we can find the forecast for the number of production movements. For the forecast of the time required in the future, we assume the time spent on production flow and waste flow is proportional to the movements' increment. The time spent on human flow remains the same as current status. For example, we know the time spent on human flow in 2007 was 1 hour per day at best case and 1.5 hours per day at worst case. We assume time spent on human flow remains the same in the following years. The time spent on material flow in 2007 at best case was 4.08 hours per day. The total production movement in 2007 was 7.99*912+20.18*23+20.18*4=7,863, the total production movement in 2008 will be 7.99*844+20.18*278+20.18*21=12,806, and the time spent on material flow per day in

2008 will be 4.08*12,806/7,863=6.64 hours. Similar philosophy has been applied to the following years. So the forecast result can be summarized in Table 9.

Table 9 Future capacity utilization forecast

Duration(best)	2008	2009	2010	2011	2012	2013	2014	2015	2016
Human	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Material	6.64	8.80	13.10	17.00	21.88	26.41	31.27	35.95	39.46
Waste	1.63	2.16	3.21	4.17	5.36	6.48	7.67	8.81	9.68
Total	9.27	11.96	17.31	22.16	28.24	33.89	39.94	45.76	50.14
Utilization	23.8%	30.7%	44.4%	56.8%	72.4%	86.9%	102.4%	117.3%	128.6%
Duration(worst)									
Human	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Material	7.63	10.11	15.05	19.53	25.14	30.35	35.93	41.31	45.34
Waste	2.44	3.24	4.82	6.25	8.05	9.71	11.50	13.22	14.51
Total	11.57	14.85	21.37	27.28	34.69	41.56	48.94	56.03	61.36
Utilization	29.7%	38.1%	54.8%	69.9%	88.9%	106.6%	125.5%	143.7%	157.3%

As we can see from the table, in around 2013, the utilization will exceed 100%. For the worst case, the utilization in 2013 will be 106.6%. The total available hours per day are 39. So the 6.6% exceeded utilization means there are 6.6%*39=2.57 hours production hour loss per day on average.

2.5.3 Utilization Cap

This utilization cap description is taken from my teammate Mr. Yizhe Cen's thesis, section 5.4.

In order to determine the utilization cap that translates into acceptable performance level, we first need to understand the relation between the capacity utilization and the performance of the material handling system. We simulated the system performance at various capacity utilizations by assuming that the variability of the daily movements would have the same pattern as 2007. For instance we scaled each daily number of movements in 2007 by the same proportion to achieve the average capacity utilization of 70%. The worst case of the current capacity utilization of 19.7% is taken as the conservative estimate. We know that the daily average number of movements in 2007 is 21.95. The number of movements that can be handled, denoted by Cap, is calculated as below.

$$Cap = 21.95/19.7\% = 111.4\ movements/day$$

At 70% utilization, the average number of daily movements, u' is calculated as below.

$$u' = cap \times 70\% = 111.4 \times 70\% = 77.99$$

To simulate operating at 70% utilization we scale each daily number of movements in 2007 by the same proportion as the average number of daily movements; in this way we can approximate the variability of movements at 70% utilization.

After approximating the variability of movements, we use a simple queuing model to understand the performance of material handling with the movement data in 2007. For this simulation we assume that the maximum number of movements per day is given by Cap = 111 movements per day. For a given utilization level, we then determine the key performance statistics for the system by simulating the processing of the scaled movement from 2007. Three important performance statistics were measured as the output to the queuing model—W, the average waiting time for the pallets, Q, the average number of pallets left over at the end of the day and Max Q, the maximum number of pallets left over at the end of the day.

Table 10 Snapshot of the queuing model analysis to determine the performance at 70% utilization

Day	Daily movements in 2007	Daily movements at 70% utilization	Q0	Q1
1	23	93	93	0
2	30	122	122	11
3	19	77	88	0
4	35	142	142	31
5	12	49	80	0
6	18	73	73	0
7	32	130	130	19
8	45	183	202	91
9	15	61	152	41

A snapshot of the analysis for the first nine days is shown in Table 10 for the case of 70% utilization. We assume all the movement requests arrive in the beginning of the day and the daily capacity is fixed at 111 movements/day. The movement requests that exceed the daily capacity are carried over to the next day. Q0 records the queue length at the beginning of the day and Q1 records the queue length at the end of the day. We calculate Q, Max Q and W based on the equations below.

$$Q = Average(Q1)$$

$$Q\% = Q / u'$$

$$Max\ Q = Maximum(Q1)$$

$$Max\ Q\% = Max\ Q / u'$$

$$W = Q / u'$$

The queuing model was tested at five possible capacity utilization levels—60%, 65%, 70% 75% and 80%. As shown in Table 11, all three performance measures get larger as the utilization cap increases. For the 70% utilization level, each pallet has to wait for about 6.5 hours on average and there is 27% of the chance that the movements cannot be completed within the same day. In addition, the movements that ought to be completed in one day might have to be postponed by 2.9 days at most.

Table 11 Material handling performance under three utilization caps

Utilization	W	Q%	Max Q%
60%	2.2	9%	212%
65%	3.6	15%	240%
70%	6.5	27%	291%
75%	14.3	60%	429%
80%	25.6	107%	746%

Based on the expectation of NPC, Singapore's material handling operations, 70% is the maximum acceptable utilization cap. That is, NPC regards the performance measures at 70% utilization to be acceptable, whereas these measures are not acceptable for any higher utilization. Thus we use 70% as the benchmark to determine when the capacity problem will occur and when the solutions shall be implemented.

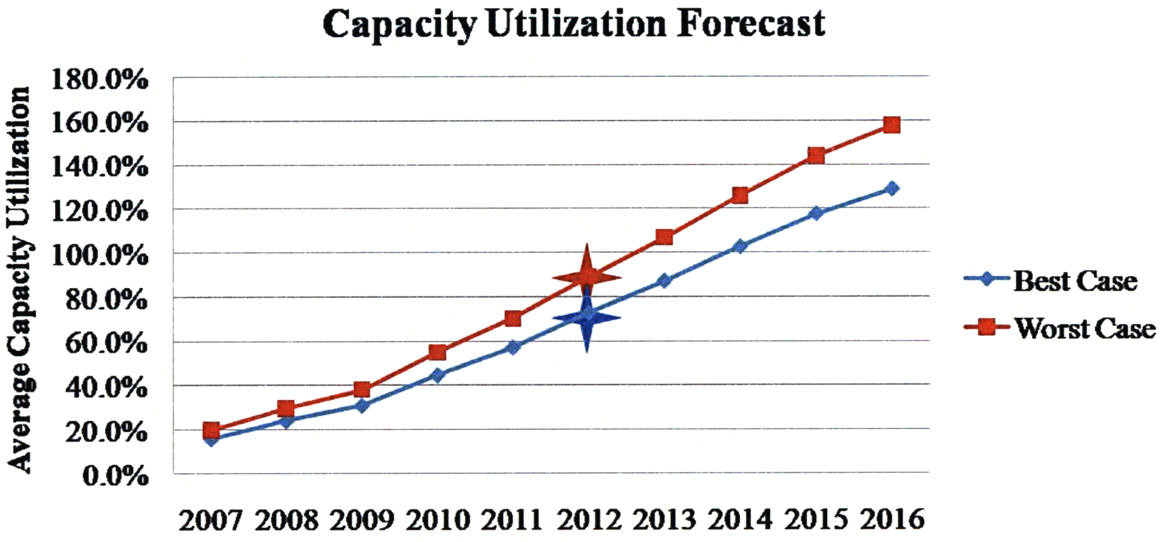


Figure 10 Capacity utilization forecast

As shown in Figure 10, the capacity utilization exceeds the capacity cap by year 2012 for both the best case and the worst case. This suggests that we shall implement solutions in 2011, which gives us a window of about 4 years before the current capacity is to be over-utilized. In order to provide the solutions, we first need to understand what it means for over-utilized capacity and what sources of time spent are driving this capacity problem.

2.6 Objective

The common objective for material handling is to improve the operational efficiency and capacity to meet the production requirement. For our project, the first objective is to investigate the current material handling. Secondly, we need to validate whether there are capacity and efficiency problems in the current material handling model. The third one is to determine possible solutions for improvement and the returns on investment by applying the solutions. As mentioned in section 1.4 about the organization of the thesis, this thesis will focus on examining the automation of the transportation. Finally, by comparing the solutions, we will present a conclusion and a summary of the solutions implementation timeline.

3. Review of the Previous Work

This chapter is aim to review some of the previous work people have done on automating the material handling via AGVs, also summarize the AGV implementation model in NPC US site. From this, we can develop our design details on the performance of AGVs.

Material handling is one of the key parts of the whole operational system. According to Tompkins and White, material handling cost takes 20-50% out of the total operational cost. [6] Since currently most of the material handling in industrial areas is done manually, the efficiency and capacity won't be sustainable as the production volume increases. Therefore plenty of research focuses on implementing automatic technology in material handling systems to improve the efficiency and capacity. This thesis is going to discuss in detail the performance of AGV implementation. This includes the task determination, the delivery and dispatching rules determination, the operating speed for the AGV and the interface between the AGV and the materials.

Firstly, there are several important papers related to determine tasks and the delivery and dispatching rules. Egbelu and Tanchoco classified AGV dispatching rules into two categories: work-centre-initiated rules and vehicle-initiated rules.[7] Work-center-initiated rules select a vehicle from a set of currently idle vehicles and assign the vehicle to a unit-load pickup task generated at a workstation. Vehicle-initiated rules select a work centre from a set of work centers simultaneously requesting for the transport service of vehicles. Task determination and the delivery and dispatching rules were also investigated by Y.-C. Ho* and S.-H. Chien. They presented 10 rules, which includes shortest distance rule, Smallest-remaining-processing-time rule, Combination rule, Smallest-input-queue rule, Longest-time-in-system rule, Longest-time-on-vehicle rule, Earliest-due-time rule, Longest-elapsed-time-since-last-arrival rule, Smallest-slack-time rule, Random rule. [1] The common goal of these rules is to operate the material handling system at a high efficiency with minimum programming cost. To determine which rule should be implemented depends on the requirement of different material handling system. For example, if the company wants to ensure that all the demand from their customers can be fulfilled, they should choose the earliest-due-time rule.

The operating speed for AGVs actually depends on the model and design of the AGV. Satoshi Hoshino and Jun Ota investigated that on average the speed of an AGV could be up to 7 meters per second while it is empty and could be up to 5.6 meters per second while it is full. [2]

In NPC US site, five AGVs have been implemented in 1998. Firstly they intend to use AGVs as the transportation between production and the warehouse; however, since the warehouse is not connected to the pharmaceutical facilities, AGVs were not suitable for the working condition there. So they use the AGVs for the internal movements within the warehouse. A kind of power roller conveyor, they called it smart conveyor, was used as the interface between the AGVs and the materials. In addition, twelve cranes were implemented as the interface between AGVs and the rack places in the warehouse. AGVs will load or unload the materials from smart conveyors and move them to the crane, and then the crane will move the materials to the desired rack place in the warehouse.

4. Methodology

There are two key parts of this project. The first part is to investigate whether there are capacity or efficiency problems in the current material handling model. The second one is to develop and evaluate solutions to solve the problem.

To investigate the capacity problems of the current material handling model, we forecasted the utilization of material handling resources in section 2.5. Firstly, we understood the types, numbers and variation of the material movements through floor observation and communication with the warehouse and production personnel. Secondly, we recorded time taken per movement to identify the drivers of the large time taken per movement. Thirdly, we determined the current capacity utilization and then we made forecast of the future capacity utilization. Finally, we established the problem consequence.

Once we have established the problem with the current material handling system, the approaches to solve the problem need to be tested. There are two major directions of the approaches. The first one is to reduce the cycle time per movement, so the total time spent on material movements along the spine will be reduced, and then the utilization in terms of total time spent on material movements along the spine per day over the total available man hour per day will be reduced as well. The second one is to increase the system capacity, so more material movements could be handled in the same time, which means the capacity has been increased.

From the utilization reduction perspective, in section 2.4, we notice that time spent on space adjustment in staging areas and transportation between warehouse and staging areas are the two major parts of total time per movement along the spine. Before thinking about reducing these two parts, we investigated the reasons for the longer time spent on these two parts first, and then apply appropriate automation technology, such as conveyors implementation to automate the staging areas or automation vehicles implementation to automate the transportation. To justify whether the new technology implementation is cost-efficient, the financial analysis will be applied. We will compare three major financial parameters with the NPC Singapore standard, to justify whether the investment is economical from the company perspective. The three parameters are net present value, payback period and internal rate of return.

From the capacity increment perspective, firstly the increment can be realized by adding more shifts, labors and forklift trucks. Secondly, since the load capacity of automation vehicles are larger than the current forklift trucks, automating the transportation via automation vehicles can also increase the system capacity. Therefore, we will compare this two solutions from the financial perspective and eventually present the most cost-effective solution.

5. Analysis and Discussion of Solutions

As we mentioned before, mainly four solutions for solving the problem in the current material handling system will be investigated. The four solutions include inventory management and Kanban Layout redesign, automation implementation in staging area, forklift trucks extension, and automation implementation in transportation and then extension to the fully automatic material handling system. Kanban Layout redesign and conveyor implementation have been discussed in Mr. Yizhe Cen's thesis. In this thesis we will take the conveyor implementation as a starting solution; the conveyor implementation will facilitate the implementation of automation vehicles as it provides the interface between the vehicles and the materials in an automatic system. This chapter will focus on the last solution, namely automating the transportation. And we will make a comparison between automating the transportation and purchasing more forklift trucks to improve the system capacity. Finally we will provide the most cost-effective solution.

5.1 Overview of Automating Transportation

From section 2.4, we knew that time spent on transportation takes a large part of the time spent on movements along the spine. And the reason why transportation between the warehouse and production takes so much time is mainly because the loading and unloading process consumes much time. As mentioned before, currently the movements between the warehouse and production are transported manually via forklift trucks. So currently the loading and unloading process requires the workers operate the forklift trucks very carefully and make sure the pallet on the forklift truck could be moved into a fine position, which normally required lots of time. The aim of automating the transportation is to reduce the total time spent on transportation, including the loading and unloading time and traffic time. There are many automatic technologies available. To determine what kind of technologies will be appropriate, there are two major measures: the throughput and the working path distance. The details are shown in Figure 11. [5]

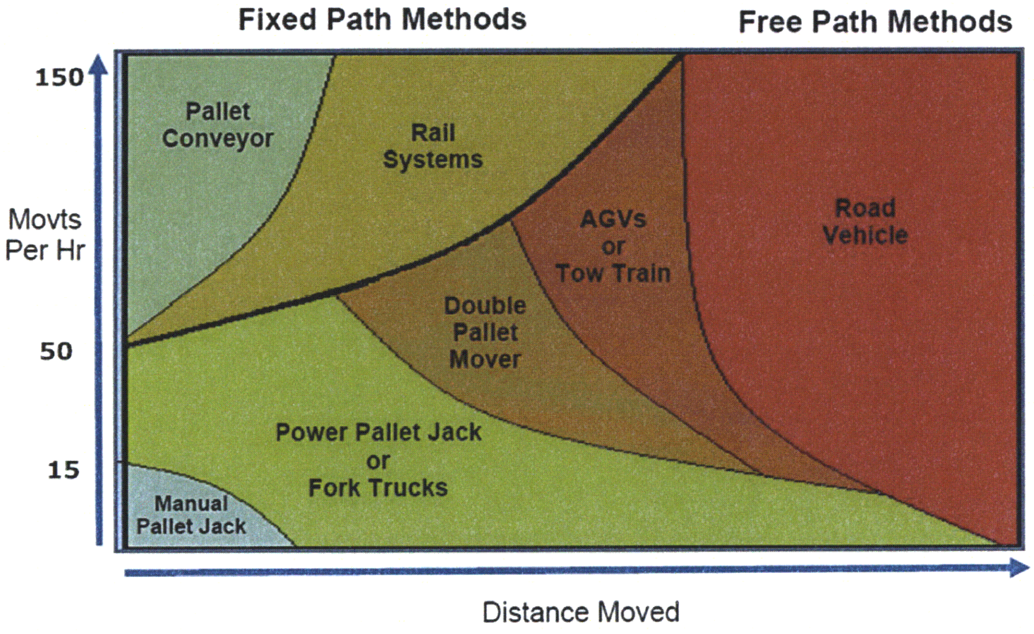


Figure 11 Technology selection via throughput and working path

In order to achieve better operational efficiency, there are two appropriate technologies to automate the transportation: AGV (Automated Guided Vehicle), and transfer cars, which are track oriented vehicles. According to the vendors, transfer cars can operate at the same efficiency as AGVs, and they also can share the same working model. But the price of a transfer car is 50% less than an AGV. Therefore, due to the complexity of the AGV, we will use AGV implementation to illustrate the working model details, and differentiate them in the financial analysis part.

Regarding the design details about working model of AGVs, firstly the number of AGVs will be implemented need to be determined. Secondly, the key problem is to determine transportation model and interface between the vehicles and the loading, unloading spots. The number of AGVs being implemented will be discussed in next section.

Regarding the transportation model, we need to determine the load pick up rule for the AGV. This means after finishing a movement, the AGV needs to determine where it goes next to move the materials there. Y.-C. Ho* and S.-H. Chien investigated ten delivery and dispatching rules as mentioned in section 3. [1] The same rules can be applied to determining the load pick up. The common purpose for applying them is to ensure the operational efficiency with lowest complexity. Due to the low throughput and the low complexity working path, for this project, we recommended applying the shortest distance rule as the load pick up rule in pharmaceutical facility areas and first in first out service rule as the load pick up rule in the warehouse, which is demonstrated in Figure 12.

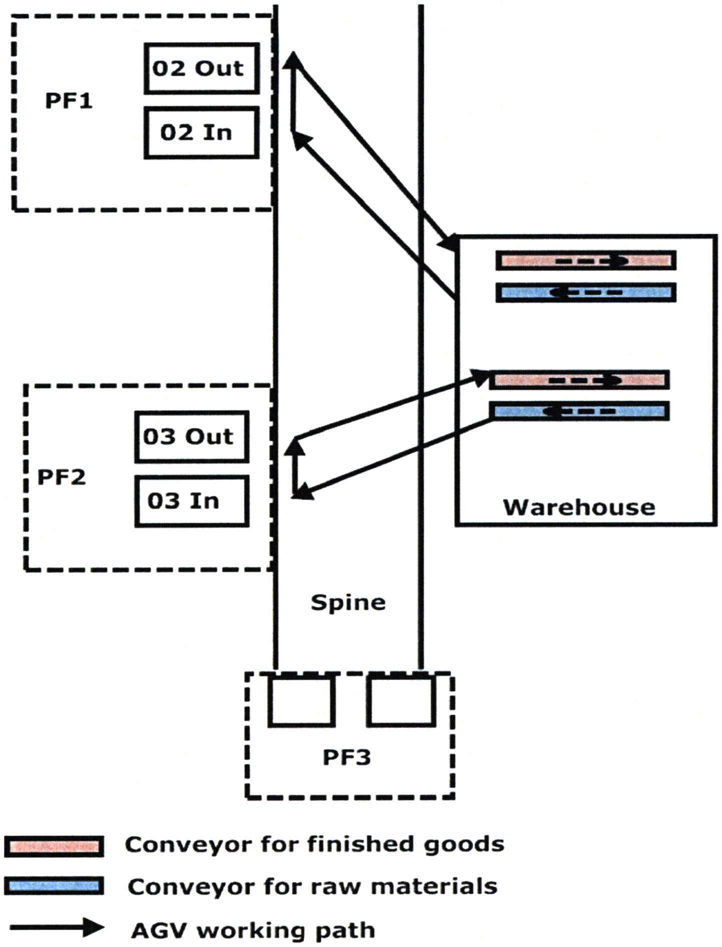


Figure 12 AGV working model flowchart

This figure basically shows the flowchart for the AGV working between the warehouse and pharmaceutical facilities based on the shortest distance rule among production and first in first out rule within the warehouse. For example, if the AGV from the warehouse sends RW_A3 to 02 Stage In area in pharmaceutical facility 1, after finishing this raw material sent movement, based on the shortest distance rule, the distance from the current spot to other loading and unloading spots can be calculated and the one with the shortest distance from the current spot will be chosen as the next picking spot. This means 02 Stage Out, which is the nearest to 02 Stage In will be chosen as the next pick up spot, so the AGV will go directly to 02 Stage Out to pick up the finished goods for Product A and then bring them back to the warehouse. While going back to the warehouse and completing the finish goods movements, AGV will follow the first in and first out rule to determine which movement needs to be done next.

Regarding the interface between the vehicles and the materials, as we already mentioned, according to Mr. Yizhe Cen's thesis, we recommend implementing conveyors in staging areas in 2011, and those conveyors can be used as the interface between the automation vehicle and the materials in staging areas. Similarly, we recommend still using conveyors as the interface between vehicles and the materials in the warehouse, as shown in Figure 12. As we can see, we recommend there will be a centralized loading and unloading area in the warehouse for each pharmaceutical facility, and each centralized loading and unloading area includes a raw materials conveyor and a finished goods conveyor.

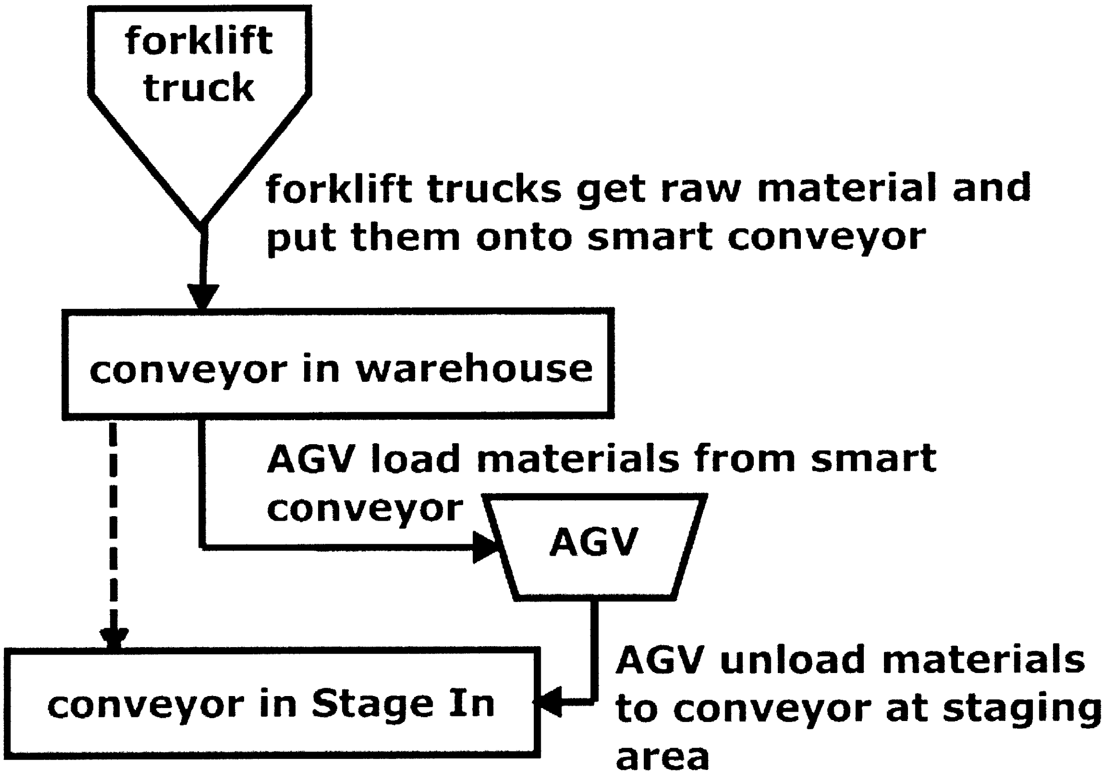
As mentioned at the beginning of this chapter, in order to reduce the time spent on space adjustment in staging areas, we recommend conveyor implementation in staging areas. The detailed discussion has been covered in Mr. Yizhe Cen's thesis. Conveyors implemented as loading and unloading equipment can be a very good way to achieve the interface between the materials and the vehicle. The conveyors can cooperate with the AGV to realize the pick up and delivery of materials very easily and conveniently. Similarly for the warehouse, conveyors can be implemented in the centralized loading and unloading area as the interface between the vehicle and the materials. With the help of conveyors, the FIFO pick up and delivery rule can be easily achieved. In addition, the centralized loading and unloading design is more economical than distributed design. However, while setting a centralized loading and unloading spot in the warehouse, the internal movements within the warehouse will increase. We need to determine how to handle these internal movements. There are two ways to handle this. Firstly, we can keep the current way that in which internal movements are transported via forklift trucks, these forklift trucks can interact with the AGV and conveyors; we term the whole material handling to be a semi-automatic system. Secondly, we can develop a fully automatic system. The internal movements can also be done by AGVs. However, this is more appropriate as a future plan for NPC Singapore. Therefore, in the next section, we will emphasize the consideration of the semi-automatic material handling system.

5.2 Semi-automatic Material Handling System

In the semi-automatic material handling system, we recommend to use automation vehicles, namely AGVs or transfer cars, to automate the transportation between the production and the warehouse along the spine. And the internal movements within the warehouse are still done via the current forklift trucks. Because currently the warehouse has four horizontal forklift trucks, and two vertical forklift trucks, namely VNA (Very Narrow Aisle Truck). They were purchased in 2000, 2003 and 2006. Generally the life time for a forklift truck is 15 years. By the time we want to automate the transportation, they are still in their life cycle. Therefore, in short term, we will discuss the implementation of a semi-automatic material handling system first.

5.2.1 Overview of Semi-automatic Working Model Flowchart

For raw materials sent from the warehouse to production, they first need to be moved from the storage racks to the centralized loading area via forklift trucks. At the centralized loading area the forklift trucks will place the raw materials on the conveyors. An AGV will pick up the raw materials from the centralized loading area and bring the raw materials to the Stage In areas. The conveyors at Stage In area will receive the raw materials delivered by the AGV, and then send the raw materials for production. The working process is described as shown in Figure 13.



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in the future, conveyors could be extended and link to the conveyor in staging areas directly, so AGV could be eliminated.

Figure 13 AGV working model (raw materials movements)

For finished goods moved from production to the warehouse, an AGV will pick them up from the conveyors at Stage Out areas, and bring them onto the conveyors at the centralized loading and unloading area in the warehouse. At the centralized loading/unloading area the forklift trucks will pick up the finished goods and bring them to the desired rack places. The working process is described as shown in Figure 14.

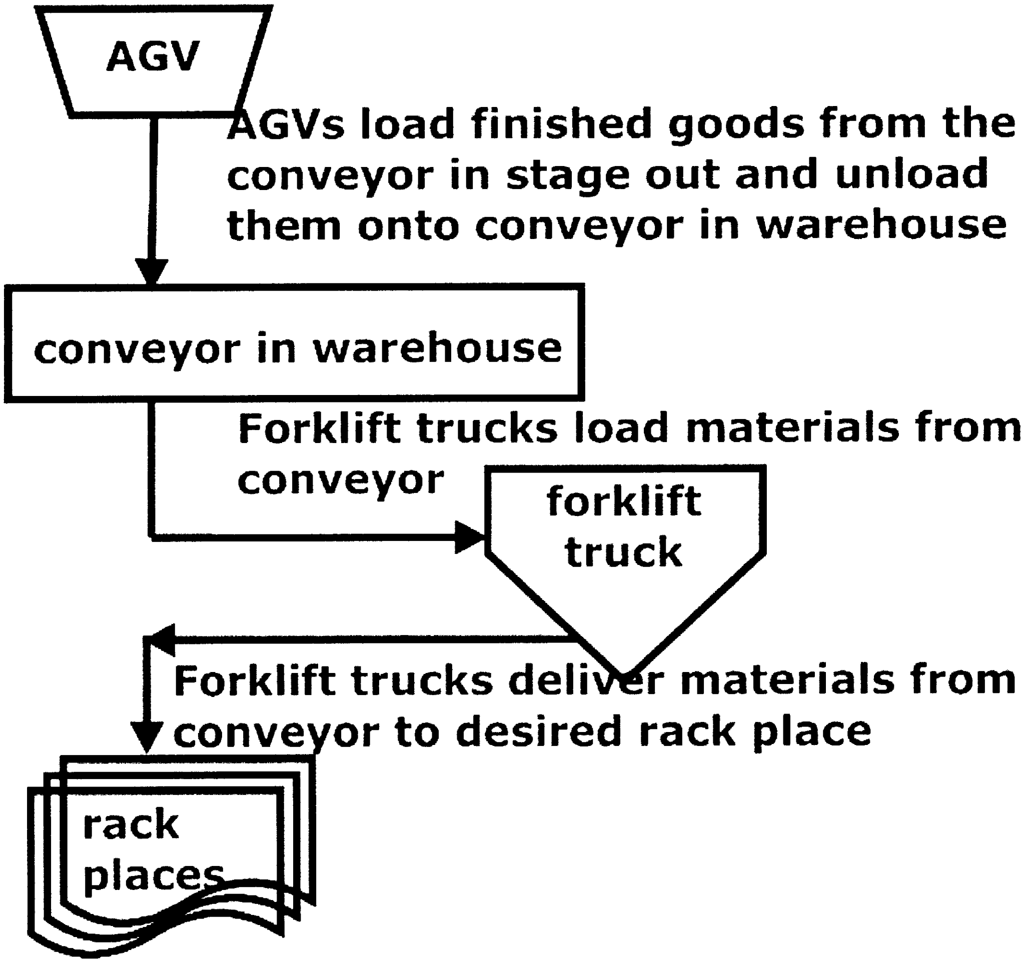

Figure 14 AGV working model (finished goods movements)

5.2.2 Advantage of Automation Vehicles in Transportation

There are two major advantages of automation vehicles in transportation. Firstly, from the efficiency perspective, the automation vehicles run faster than current forklift trucks. In addition, with the help of conveyors as the interface between vehicles and materials, the loading and unloading time could be sharply reduced as well. Secondly, from the capacity perspective, the load capacity for the automation vehicles is higher than forklift trucks. The load capacity for automation vehicles is up from 1,000lbs to 10,000 lbs, which means they can handle at least two of our current pallets of materials.

First we will talk about the efficiency perspective. The transportation speed for the current forklift truck is from 1.5meters per second to 2.5 meters per second. And the speed of the AGV could be two to three times higher than the current speed of the forklift truck. [2] And due to the pre-programmed working path, the loading and unloading process for the AGV will be faster than for forklift trucks. This means the transportation time spent for an AGV should be at most half of the transportation time spent for a forklift truck. For calculating convenience, here we assume the transportation time spent will be reduced to exactly by half of the current one in the semi-automatic material handling system. In addition, there will be time reduction per movement due to conveyor implementation as well. As discussed in Mr. Yizhe Cen's thesis, with the conveyor implementation in staging areas, the previous time spent on space adjustment due to pallet space misallocation and violation of FIFO rule can be eliminated. However, with the conveyor implementation, there will be another time consuming factor that we need to consider. That is the waiting time. Since each pallet place is arranged for a certain raw material, every time when the warehouse personnel or the production personnel reach the conveyors, they might not face the exact pallet place. For that matter, they need to press the operating button of the conveyors to rotate the pallet places until the right pallet of raw material is facing them. Therefore, the waiting time for the conveyor movement needs to be considered. Generally, the speed of conveyor is 27 to 86 feet per minute. [8] For our design, the speed should be around 30 feet per minute, which is around 0.152 meter per second. And the total length for our conveyor design is 720 inches. So the longest waiting time won't be higher than 120 second. Therefore, we assume with the help of conveyors, the space arrangement time could be reduced to 1 minute. For that matter, the time spent on finished goods moves for automation vehicles will be 37% less than for a forklift truck, and same on raw material moves, as shown in Figure 15 and Figure 16 .

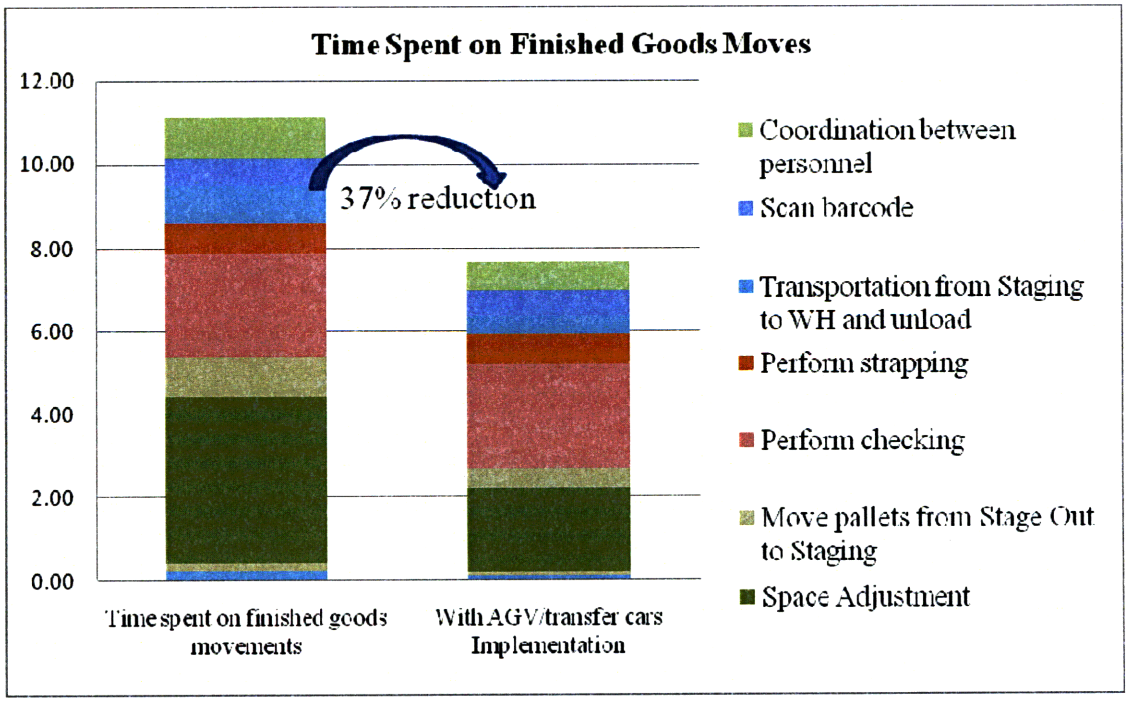

Figure 15 Time taken comparison between current system and semi-automatic system (finished goods)

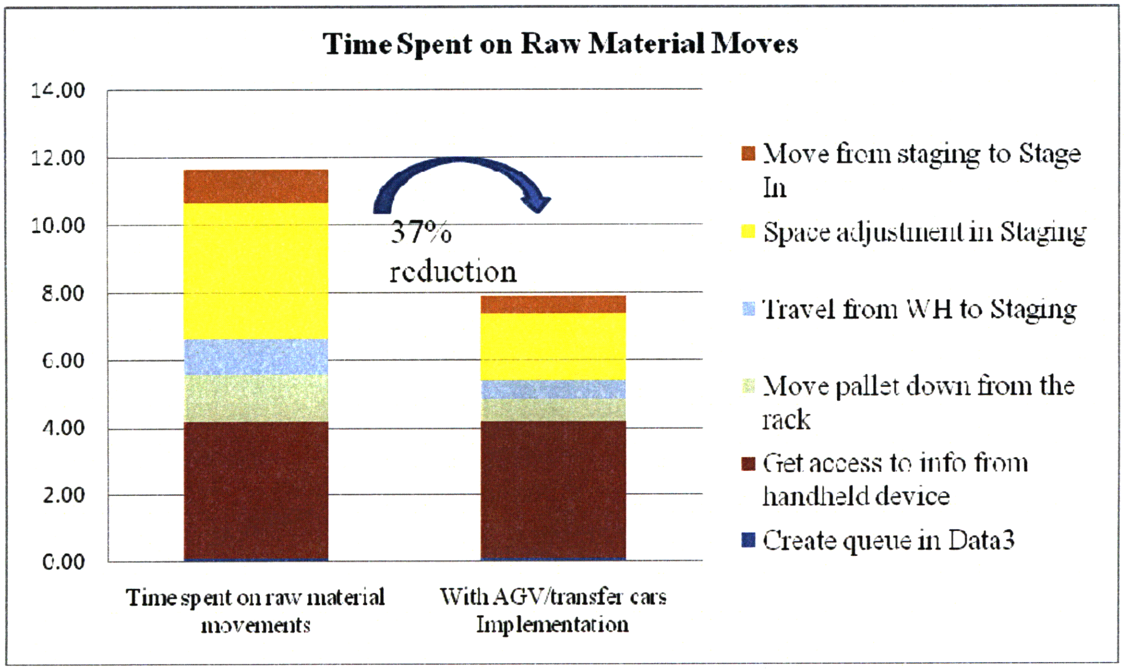

Figure 16 Time taken comparison between current system and semi-automatic system (raw material)

From the capacity perspective, automation vehicles are able to carry more than one standard size container. Currently, all the raw materials are moved pallet by pallet via forklift trucks. So if we double stack the pallets of raw materials onto automation vehicles, this means the capacity of automation vehicles could be twice as great as that for the forklift trucks.

5.2.3 Determination of the Working Model Details

Since we already know the time taken per movement for both forklift trucks and automation vehicles, and we also know the effective working hours for both of them, which is 13 hours for forklift truck and 18 hours for automation vehicles, this means we can calculate the capacity for both of them. The capacity means the daily number of movements they can handle, which equals the total effective working hours divided by the time taken per movement. Specifically, the total effective working hours for a forklift truck are 13. The time taken per movement for a forklift truck varies from 11.14 minutes to 12.8 minutes. The utilization cap for forklift trucks is 70%. Therefore, the total number of movements that a forklift truck can handle per day is 42-49 (49=70%*13/(11.14/60); 42=70%*13/(12.8/60)). The utilization cap for AGVs is also 70%. So we apply the same method to calculate the capacity of an AGV; we find that an AGV can handle 168-178 movements/day. We will use this to justify our determination of the automation system working model.

In section 2.5, we mentioned how we calculated the number of movements per batch for each product. And with the forecast of the production volume in batches, we will achieve the yearly total number of movements along the spine. By using the same method, we also can find the yearly total number of movements between three pharmaceutical facilities and the warehouse. We divided the results by 358 to obtain the daily throughput. The chart is shown in Table 15. The x axis is the year, and the y axis is the number of daily movements along the spine.

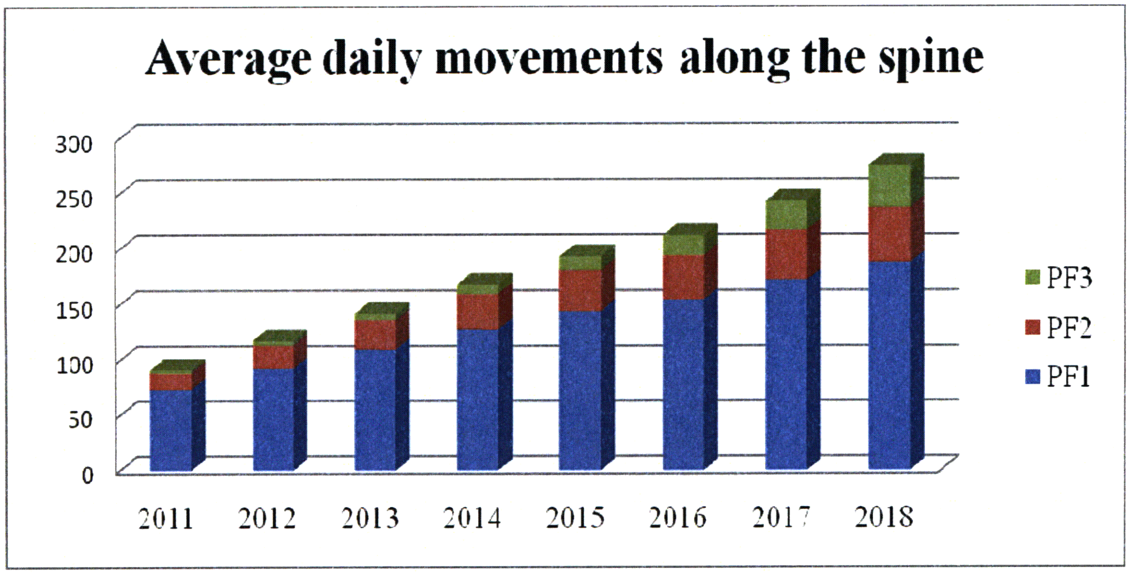

Figure 17 Average daily movements along the spine in three PFs

As we can see from the chart, the throughput of PF3 is not very high. But the throughput of PF 1 and PF 2 are much higher. In addition, the daily movements are far beyond the capacity of three forklift trucks. On the other hand, up until 2018, the throughput of PF 1 and PF 2 are still within the capacity of a single AGV. Therefore, to automate the transportation between production and the warehouse, we recommend to automate the transportation between PF 1, PF 2 and the warehouse first. Each pharmaceutical facility requires one AGV, so we need to implement two AGVs first. For PF 3, we recommend to keep one of the current forklift trucks doing the movements between it and the warehouse.

5.2.4 Capacity Utilization Improvement

According the Yizhe Cen's thesis, by implementing conveyors in staging areas in 2011, the system capacity will be sufficient until 2013. So in order to increase to system capacity, further solutions need to be implemented. Therefore, we recommend to automate the transportation in 2012. Given the time spent per movement for automation vehicles and two automation vehicles will be implemented in 2012, we plug the numbers into our previous capacity utilization forecast model. We can get the results as shown in Table 12.

Table 12 Capacity Utilization of the two automation vehicles

	2012	2013	2014	2015	2016	2017	2018
Utilization of AGV (Best Case)	25.5%	30.8%	36.5%	42.0%	46.1%	52.8%	59.7%
Utilization of AGV (Worst Case)	31.5%	38.0%	45.0%	51.8%	56.8%	65.1%	73.7%

As we can see, if we automate the transportation in 2012 by implementing two automation vehicles, we have sufficient system capacity through 2018.

5.2.5 Financial Analysis

From previous section, we know that by automating the transportation by implementing either two AGVs or two transfer cars in 2012, the system capacity is sufficient up to 2018. In this section, we will compare AGV implementation and transfer car implementation from the financial perspective. Furthermore, as a comparison, we will also investigate the financial result of maintaining the current manual material handling way by adding more shifts, labors and forklift trucks so as to have sufficient system capacity through 2018. We will focus on the financial analysis for AGV first, and then for transfer cars.

From the previous analysis in section 2.5, we know that with the current system capacity in terms of manpower and forklift trucks, the capacity will not be sufficient in 2012. We assume that if we do not implement any solutions to increase the capacity, there will be some material movements that cannot be finished. For example, raw materials cannot be supplied to production from the warehouse in time, or finished goods are piled in Stage Out while warehouse personnel cannot move them back to warehouse efficiently. For that case, we assume that the company will suffer a production loss. On the other hand, if the system capacity can be increased to satisfy the requirements through 2018, we assume that we can avoid the production loss from 2012 to 2018. For example, previously, the utilization in 2012 will be 72.4%. (Here we only consider the best case for analysis.) This utilization exceeds the utilization cap by 2.4%. We assume that this 2.4% over-utilized capacity corresponds to 0.936 production hours per day, which equals 2.4% multiply total available man hour per day (39). Thus, we assume that without increasing the capacity, there will be 0.936 production hour work that cannot be finished. Similarly we obtain the production hour loss through 2018, as summarized in Table 13.

Table 13 Production hour loss from 2012 to 2018

	2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Production hour loss	0.936	6.59	12.64	18.45	22.85	29.95	37.40

From the company perspective, the most convenient way to avoid production hour loss is to hire contractors to work an additional shift, and to purchase more forklift trucks if necessary. By implementing AGVs to increase the capacity, that 2.4% daily production hour loss can be avoided. Based on the communication with the financial personnel in

NPC Singapore, the hourly pay for a contractor is 10.4 Singapore dollars. And they can work 8 hours per day and 20 days per month. The daily effective working hours are 6.5 hours as well. Therefore, from Table 13 we can infer that in order to cover the production hour that the current capacity cannot fulfill and avoid the production loss from 2012 to 2018, NPC would need to hire one contractor in 2012, add one more contractor in 2014, and another one more contractor in 2016. In 2017, NPC not only needs to hire one more contractor but also needs to purchase one more forklift truck. From 2012 to 2016, there will be three contractors added, and they will work as an additional night shift and use the current three forklift trucks. After 2016 if NPC needs to add one more contractor working on the material movements along the spine, they also need to purchase one more forklift truck for this additional contractor. According to the financial department in NPC, the expense on one forklift trucks is $50,000 Singapore dollars and the annual maintenance fee is $3,000 Singapore dollars. In 2018, NPC would need to add two more contractors, who would be assigned to the current morning shift and afternoon shift individually. In addition, NPC needs to buy two more forklift trucks for them. Therefore, for the three contractors added before 2017, they will work as an additional night shift and share the same forklift trucks with the morning and afternoon shifts, for the three contractors added in 2017 and in 2018, there is no additional shift that we can add, so each of them will be added into each shift, and NPC need to purchase three more forklift trucks for them. To sum up, in order to increase the capacity and avoid production loss, from 2012 to 2018, NPC needs to hire 6 contractors and purchase three forklift trucks. Therefore we could summarize the total expense to avoid the production hour loss by adding contractors and forklift trucks as shown in Table 14. The total expense includes the salary for contractors, the expense on purchasing additional forklift trucks and the maintenance fee of the additional forklift trucks.

Table 14 Total expense on avoiding the production hour loss by adding contractors and forklift trucks

	2012	2013	2014	2015	2016	2017	2018
Total Expense	$4,380	$30,843	$59,130	$86,323	$106,945	$193,160	$281,018

In order to test whether the automation implementation solutions are more profitable than adding contractors and forklift trucks, we use the total expense in Table 14 as the gain in the financial analysis for automation solutions. In addition, the labor reduction can be considered as another gain. In the current transportation model, three forklift trucks need three workers to operate; however, in the automatic transportation model, which will be applied in PF1 and PF2, the operators can be eliminated. As mentioned, we need to keep one forklift truck working on the movements between PF3 and the warehouse. Therefore, we can eliminate two of the current labors dedicated along the spine. The yearly payment for a warehouse technician in NPC Singapore is around $42,000 Singapore dollars. So the total labor reduction gain is 2*$42,000=$84,000. On the other hand, we need to consider the yearly expense of implementing AGVs. The major expense will be spent on the maintenance of the AGVs. Based on the communication with vendors, we got all the related quotation of AGVs, as shown in Table 15. So the financial analysis of implementing two AGVs in 2012 can be summarized as shown in Table 16.

Table 15 Control inputs for financial analysis of AGV implementation

Control Inputs:	
Discount rate	11%
Depreciation period (years)	15
Labor cost/year	$42,000

Annual maintenance expense for an AGV	$10,000
Investment for tw0 AGVs	$600,000

Table 16 Financial analysis of AGV implementation

	2012						
Investment	$600,000						
	2012	2013	2014	2015	2016	2017	2018
Cash flow (Gain)							
Production hour gains	$4,380	$30,843	$59,130	$86,323	$106,945	$193,160	$281,018
Labor reduction	$84,000	$84,000	$84,000	$84,000	$84,000	$84,000	$84,000
Total Gain	$88,380	$114,843	$143,130	$170,323	$190,945	$277,160	$365,018
Cash flow (Expense)							
Annual maintenance expense for AGVs	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
Total Expenses	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000	$20,000
Net Cash flow	$68,380	$94,843	$123,130	$150,323	$170,945	$257,160	$345,018
NPV	$132,750						
Payback period	4						
IRR	16%						

The net present value (NPV)

=68,380/(1+11%)+94,843/((1+11%)^2)+123,130/((1+11%)^3)+150,323/((1+11%)^4)+170,945/((1+11%)^5)+257,160/((1+11%)^6)+345,018/((1+11%)^7)- $600,000

=$132,750

The Internal rate of return (IRR)

Since,

68,380/(1+IRR)+94,843/((1+IRR)^2)+123,130/((1+IRR)^3)+150,323/((1+IRR)^4)+170,945/((1+IRR)^5)+257,160/((1+IRR)^6)+345,018/((1+IRR)^7)- $600,000

So,

IRR=16%

There are three standards for the financial department in NPC Singapore to judge whether an investment is profitable or not. If the investment is profitable, firstly, the net present value must be positive; secondly, the internal rate of return must be larger than 11%; thirdly, the payback period better should be smaller than three years, which depends on the investment types. To the company, here the 4 years payback period for implementing AGVs is also acceptable. Therefore, as we can notice from the previous analysis, to automate the transportation, the investment of implementing two AGVs in 2012 will be profitable.

A similar analysis can be applied on transfer cars, which can operate at the same efficiency as AGVs, but with 50% less of the price. [5] So we can make a financial analysis for implementing two transfer cars in 2012 as well. The results can be summarized as shown in Table 17.

Table 17 Financial analysis of transfer cars implementation

	2012						
Investment	$400,000						
	2012	2013	2014	2015	2016	2017	2018
Cash flow (Gain)							
Production hour gains	$4,380	$30,843	$59,130	$86,323	$106,945	$193,160	$281,018
Labor reduction	$84,000	$84,000	$84,000	$84,000	$84,000	$84,000	$84,000
Total Gain	$88,380	$114,843	$143,130	$170,323	$190,945	$277,160	$365,018
Cash flow (Expense)							
Annual maintenance expense for transfer cars	$13,333	$13,333	$13,333	$13,333	$13,333	$13,333	$13,333
Total Expenses	$13,333	$13,333	$13,333	$13,333	$13,333	$13,333	$13,333
Net Cash flow	$75,047	$101,509	$129,797	$156,989	$177,612	$263,827	$351,684

NPV	$364,165						
Payback period	3						
IRR	29%						

From the results shown in Table 17, we know that to automate the transportation by implementing two transfer cars in 2012 will be profitable too. And from the cost-effective perspective, it is even better than the AGV implementation solution. In addition, from the previous analysis, we can infer that to increase the capacity through automating the transportation is more profitable than through adding contractors and forklift trucks.

5.3 Conclusion and Summary of the Solutions

From Mr. Yizhe Cen's thesis, we knew that conveyors are recommended to implement in staging areas in 2011 to increase the capacity of the staging areas, so as to increase the operational efficiency of the material handling between the warehouse and staging areas. By doing this, the system capacity will be pushed by one year, from 2012 to 2013. The conveyors implementation is considered as a start, further solutions need to be followed to keep the system capacity sustainable. That is why we recommend implementing two transfer cars in 2012. This will keep the system sustainable until 2018. After 2018, further solutions need to be investigated, which is a long term future plan. To sum up, the solutions implementation timeline can be summarized as shown in Figure 18.

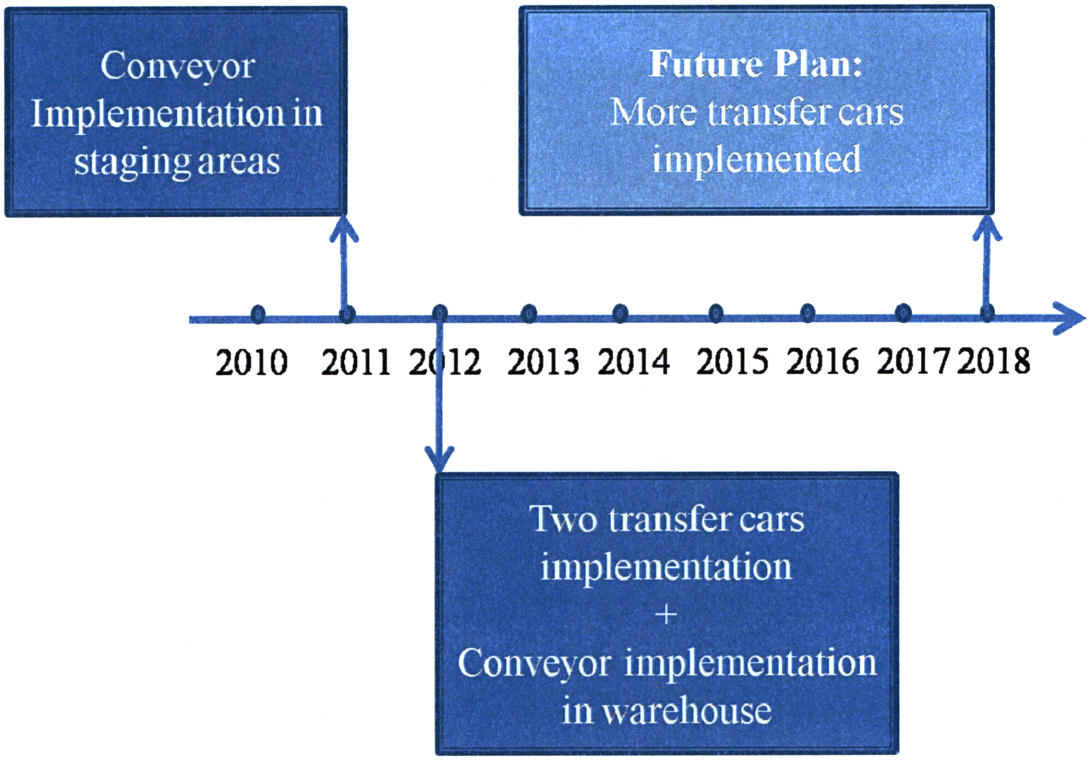

Figure 18 Solutions implementation timeline

5.4 Fully Automatic Material Handling System in Long Term

After discussing the short term implementation details, from the long term perspective, we will discuss a fully automatic material handling system as a future plan for better material handling.

The working model is actually quite similar as semi-automatic material handling system. The only difference is that in semi-automatic system, the internal material movements between the centralized loading and unloading spot in the warehouse and the desired rack places in the warehouse are transported via forklift trucks, while in the fully automatic material handling system, those internal movements can be done by central controlled cranes. This generally requires a compact storage warehouse, because it is convenient for the crane to load and unload the materials between racks and conveyors.

The operating model can be described as shown in Figure 19.

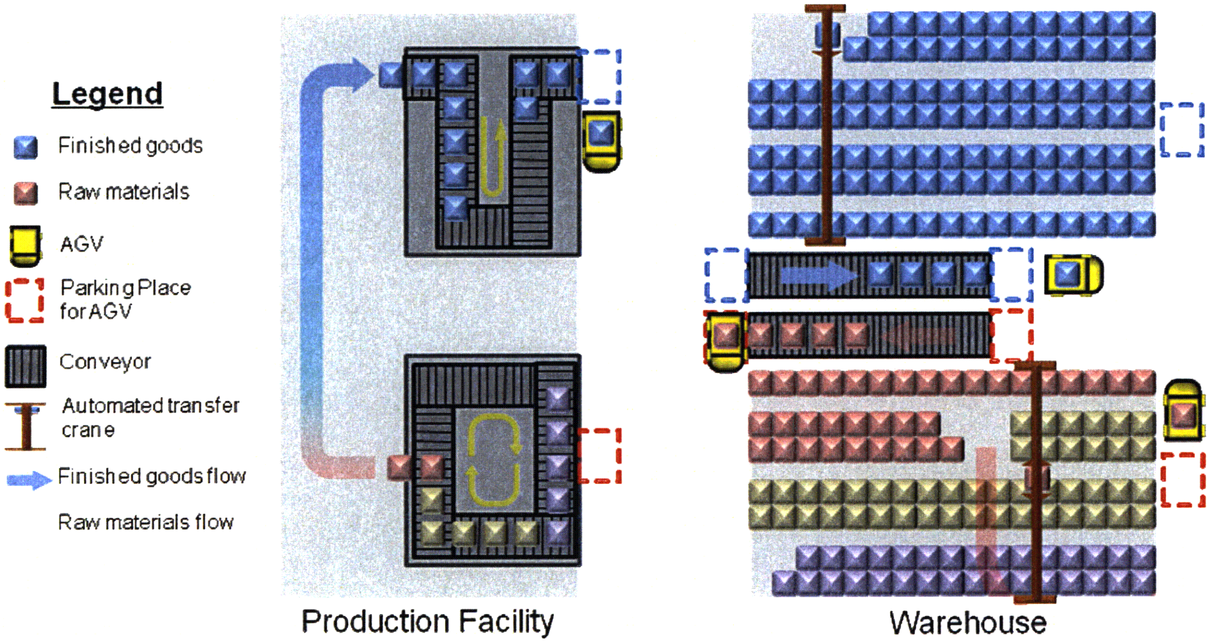

Figure 19 Fully automatic material handling system working flowchart

When there are raw materials that need to be sent to production, the centralized control station will send orders to the cranes. So the crane will pick up the raw materials from the racks, and then deliver them onto the conveyor at the centralized loading and unloading spot. Meanwhile there will be an AGV waiting in front of the conveyor, while the raw materials move to the pickup point, AGV can receive the raw materials and then bring them onto the conveyors in staging areas for production. Similarly for finished goods, after unloading them on the conveyor in the warehouse by the AGV, the centralized control station will receive a signal saying that those finished goods have been moved into the warehouse and they need to be moved to the desired rack place by cranes.

Thus far, this section presented a broad picture of a fully automatic material handling system. The detail factors still need to be further investigated in the future. The details include the accurate increase of the operational efficiency, the determination of the number of ATCs and AGVs, and financial analysis on this investment.

6. Conclusion and Recommendation with Future Works

The goal of this thesis it to identify the problems of the current material handling system, make a forecast on when the current material handling system will not be sustainable. And then investigate solutions to solve the problem and to increase the operational efficiency and capacity of the material handling along the spine. Therefore the general conclusions and recommendations can be summarized as following:

- The total number of material movements in 2007 was 14,278, 53% of which were along the spine.
- Time spent on space arrangement in staging areas and transportation between the warehouse and production are the two major parts of time spent on movements along the spine.
- With the current man power and forklift trucks, in around 2012, the system will reach its capacity limit and will sustain production loss.
- Space arrangement time could be eliminated by implementing conveyors in staging areas. The production loss situation could be postponed by one year by implementing conveyors in staging areas, as mentioned in Mr. Yizhe Cen's thesis.
- The operational efficiency of material handling also can be increased by automating the transportation. By implementing two transfer cars in 2012, the system will be sustainable until 2018. The net present value for this investment will be $364,165 and internal rate of return will be 29%.

This thesis can be considered as a start, in the future, more investigation can be made to achieve better material handling system.

- There is a basic base of the capacity forecast. It is based on the LROP. However, with the possible changes of the company policy, the LROP might change as well. If that, the forecast will change as well. But the model is still usable. Therefore, with the updated LROP, our capacity plan and utilization forecast model could be more accurate.
- This thesis focuses on discussing the capacity problem of the material handling along the spine due to the large number of movements that happen along the spine and the critical geographic location of the spine; however, it will be better that the material handling not along the spine can be further discussed in details in the future.
- In automating the transportation part, we emphasize the consideration of AGVs. The details of the implementation of transfer cars should be further examined in the future.
- The detail factors of a fully automatic system need to be further investigated. For example, the number of automated transfer cranes needed, as well as the cost analysis of the whole system.

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