Improve the Efficiency and Effectiveness of Material Handling for a Pharmaceutical Factory

by

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ABSTRACT

A sustainable and cost-effective material handling plan was developed in a pharmaceutical factory to support the rapidly growing production demand. Problem analysis was followed by the investigation of various solutions: automated guided vehicles, transfer cars, conveyors, Kanban redesign and additional forklift trucks. A return on investment (ROI) analysis was performed to justify the investment and implementation of Kanban redesign and the conveyors, which will provide sufficient capacity until year 2016. Transfer cars can be used when the demand for material handling further rises.

Thesis Advisors:

Prof. Stephen C. Graves — Abraham J. Siegel Professor of Management Science
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1 Introduction

1.1 Background

This thesis is the result of a seven month internship at NPC Pharmaceuticals, Singapore. NPC is a leading research-driven pharmaceutical company that discovers, develops, manufactures and markets a broad range of innovative heath care products.

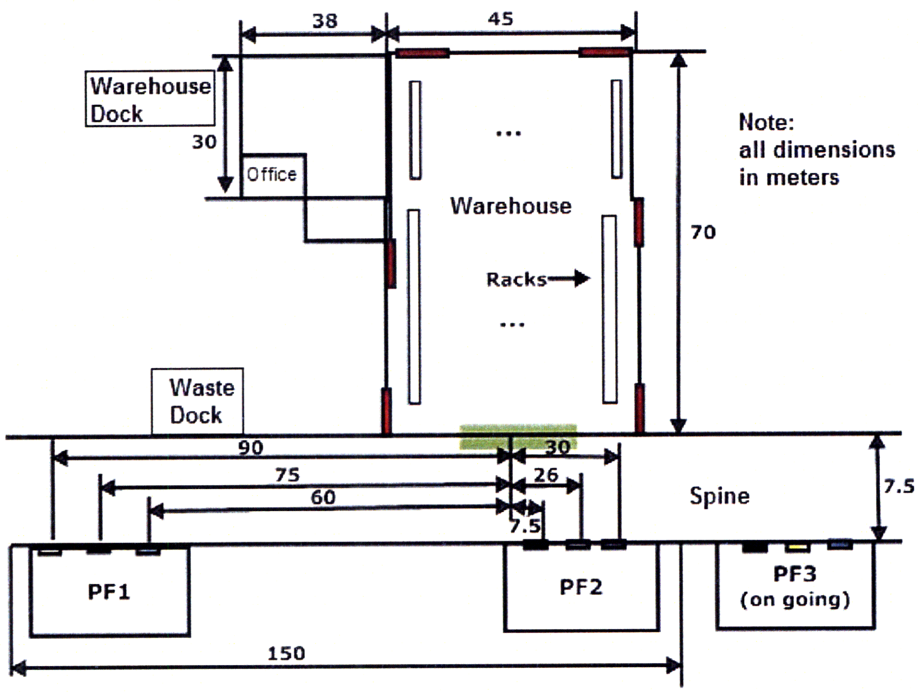

Figure 1 Floor plan of the warehouse, spine and PF facilities (not to scale)

The factory consists of two major types of facilities—the warehouse and the pharmaceutical facilities (PF). As shown in Figure 1, there are currently two PF facilities—PF1 and PF2. PF3 is expected to come on line soon. The warehouse stores, receives and supplies the raw materials and finished goods for both PF facilities. The warehouse stores materials on racks as shown in Figure 2. There are 15 rows of racks and each rack has five levels.

Figure 2 Illustration of a five-level rack

The warehouse and the PF facilities are connected by the "spine" which is a 7.5m wide and 180m long corridor. There are three staging areas (temporary storage areas) for each PF facility—Stage In for raw materials to be supplied to production, Stage Out for finished goods to be sent to the warehouse, Waste Staging for production wastes to be sent to the waste dock.

The spine is the strategic connection between the warehouse and production. The material handling is defined as the material movements between the warehouse and the production facilities along the spine. A movement typically begins with loading materials onto a vehicle, traveling from the source to the destination, and ends with unloading of materials onto the designated location. As the production rate increases, to sustain the material handling with the right technology and at a competitive cost has become essential. Therefore the analysis of material handling is important to improve the effectiveness and efficiency of the operations.

1.2 Product Description

NPC, Singapore currently manufactures two families of products for the global market—Product A and Product B. PF1 produces into two batch sizes—Product A-7 and Product A-9. Each type of Product A is produced in four strengths, which differ based on the relative concentration of the active ingredient. PF1 also performs the first stage of production for Product B, with the remaining stages executed in PF2. Product B also has two types—Product B1 and Product B2. Product B2 requires one more raw material than Product B1. A new product—Product C is planned for production in the PF3 as shown in Table 1.

Table 1 List of products in NPC, Singapore

Product Family	Product	Production Facility
Product A	Product A-7	PF1
	Product A-9	PF1
Product B	Product B1	PF1 and PF2
	Product B2	PF1 and PF2
Product C	Product C	PF3 (under construction)

The movements of all raw materials are similar, as they are all carried on pallets. However the frequency of movements differs, as the required amount per batch of production is different for each of the raw materials. The size of the container for each raw material is also different which translates into a different number of containers that each pallet can take. There can be up to nine drums per pallet for the small drums, while there is only one Flexible Intermediate Bulk Containers (FIBC) per pallet. All the raw materials of Product A are stored in PF1 Stage In temporarily before being pulled into production in PF1. All the raw materials of Product B are also stored in PF1 Stage In except for one raw material which is stored in PF2 Stage In. At any one time PF1 produces only one type of product among Product A-7, Product A-9 and Product B1. Product B2 has one more raw material than Product B1, thus the other raw materials of Product B2 are stored in the same places at Product B1. It replaces the production of Product B1 at the request of customer demand.

1.3 Problem Context and Motivation of the Internship

All the raw materials and finished goods are stored in drums or FIBC. The drums and FIBCs are placed on pallets. Each pallet can carry one FIBC or 3-10 drums depending on the size of the drum. Currently the material movements along the spine are performed by three motorized forklift trucks, each driven by a warehouse worker.

There are three problems with the current material handling system. Firstly material handling could be a bottleneck to production in the future. About 6,000 pallet movements were performed in 2007. This number is projected to grow over ten times by year 2016, given the rapid growth in the long term production plan. There will be two consequences if material handling becomes the plant bottleneck: the production would be starved with insufficient raw material supplies and the staging areas would be clogged with finished products and waste that blocks production.

Secondly the safety issue is always the top priority in NPC. More forklift trucks cannot be simply deployed to handle the excess movements. The spine space is limited and there could be traffic congestion with more forklift trucks. Even with only three forklift trucks on the spine, accidents have happened with trucks hitting the walls of the spine. This gives some motivation to investigate automation technologies to replace the manual material handling.

Lastly having a sustainable system for material handling to support the rapidly growing production is one of the keys to success in modern manufacturing. The sustainability and competitiveness of the current material handling need to be re-assessed. Our study will look at the current capacity, future growth plan to support rising demand, flexibility to handle temporary demand spikes in material handling and the overall cost.

1.4 Objective

This thesis examines the material movements between the warehouse and the PF facilities along the spine. Three objectives are targeted:

1. To investigate whether there is a problem with the current material handling and determine when will the problem occur if so.
2. To interpret the consequence of the problem and understand the drivers to the problem.
3. To strategize a solution to the problem in both short run and long run.

1.5 Organization of the Thesis

Chapter 2 specifies the problem statement by introducing the types, numbers and variation of movements. Chapter 3 reviews two areas of the literature that are relevant to the problem solving—automation technologies and inventory model and queuing model. Chapter 4 presents the approach to solve the problem step by step. Chapter 5 performs the detailed problem diagnosis in order to understand where the problem is, when it will happen and what consequences it has. Chapter 6 analyzes various solutions based on both the operational competency and cost benefits. The best solution is recommended in Chapter 7 and some issues during implementation are also discussed.

This thesis study is the result of a team project with Ms. Changhui Zhao. Her thesis study—"Strategic and Operational Plan for Better Material Handling" [1] focuses on an assessment of automating the transportation by Automated Guided Vehicles (AGVs) and transfer cars. This thesis examines possible solutions and improvement opportunities in the Staging areas.

2 Problem Statement

2.1 Classification of Movements

To understand the problem, further understanding of the material movements is essential. Every movement either begins or ends at the warehouse. The movements performed by the warehouse workers can be broadly classified into movements along the spine and movements outside the spine. The former is the focus of this thesis. The movements outside the spine include picking up raw materials from the dock outside the warehouse, moving the finished goods from warehouse to the shipping dock and the internal adjustment of pallets within the warehouse itself. The types of movements along the spine are listed in Table 2.

Table 2 Types of movements along the spine

Destination	**What is being moved from the warehouse**
PF1 Stage In	• Raw materials for Products A and B • Finished goods of Product A for re-inspection
PF1 Stage Out	• Packaging materials for Product A
PF2 Stage In	• Raw materials for Product B • Packaging materials for Product B • Finished goods of Product B for re-inspection
Source	**What is being moved to the warehouse**
PF1 Stage In	• Left over raw materials of Products A and B during change of campaign
PF1 Stage Out	• Finished goods of Product A
PF2 Stage Out	• Finished goods of Product B

Stage In areas store raw materials to be supplied to the production and Stage Out areas store finished goods that are to be moved to the warehouse. The directions of the various movements are further illustrated in Figure 3. Sending of raw materials to Stage In and receiving of finished goods from Stage Out are the majority of movements. There are three additional minor movements—packaging materials, re-inspection and change of campaign. Packaging materials are empty drums, FIBCs, and cable seals, which are stored in PF1 Stage Out for Product A and PF2 Stage In for Product B. Packaging activities are performed by the production workers. Re-inspection takes place whenever a defect is spotted. The finished goods will be sent back from the warehouse to Stage Out for qualification of the defects. The material movement is tied to the schedule of production which is run in campaigns. Each campaign is dedicated to one particular type of product. The left over raw materials during the change of each campaign have to be moved back to the warehouse. In addition, there are also some production wastes which are moved directly to the waste dock and not along the spine. As shown in Figure 4, two directions of movements contribute to the majority of movements along the spine—movements from Stage Out to the warehouse for the finished goods (38.12%) and movements from the warehouse to Stage In for the raw materials (44.10%). The statistics cited are based on the analysis of the internal database which store over 50,000 movement transactions for the past 3 years.

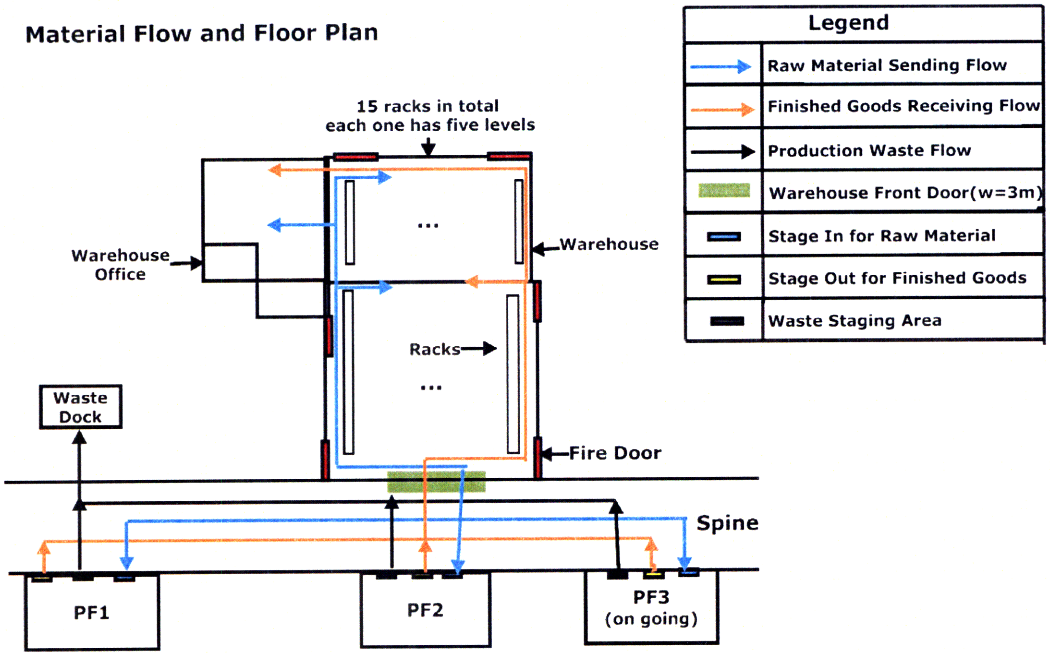

Figure 3 Illustration of types of movements along the spine

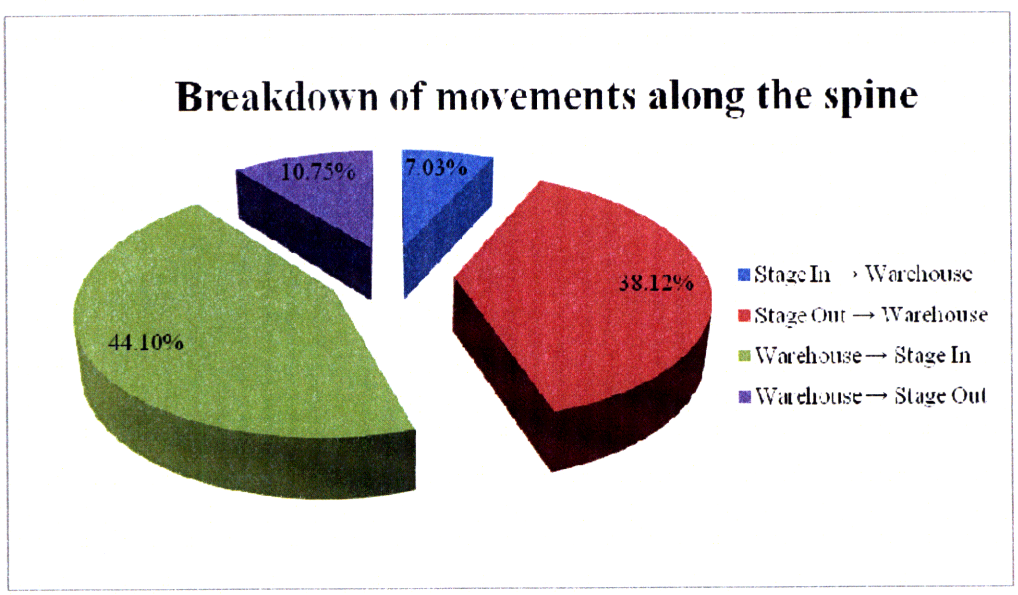

Figure 4 Breakdown of movements along the spine

2.2 Control of Material Flow

The supply of raw materials works in a Kanban-based pull system. A Kanban is placed at each Stage In for each raw material to control the material flow. The Kanban layout for Product A in PF1 Stage In is shown in Figure 5.

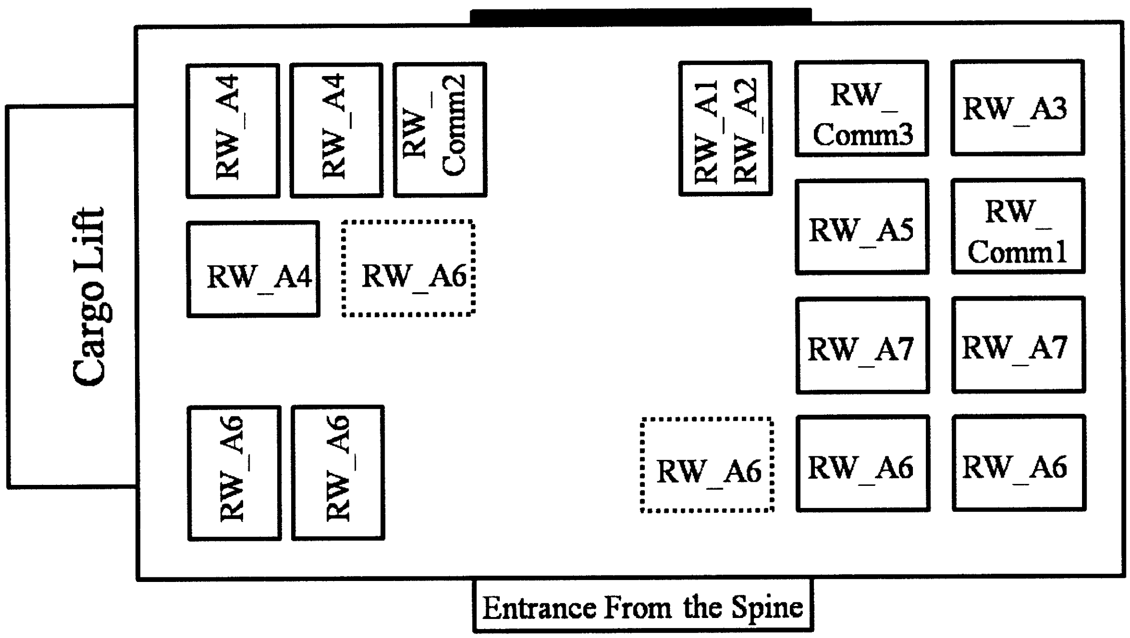

Figure 5 Kanban layout of raw materials of Product A in PF1 Stage In

Each square represents a Kanban for a particular raw material and correspond to one pallet worth of the raw material. Certain pallet space is allocated to each raw material as indicated in the Kanban layout. Three times a day (7:30 am, 2:30 pm and 10:30 pm) the warehouse workers come to the Stage In areas to check if any pallet space is empty. They will then fill in any empty pallet space. The pallet space in dash lines is only filled in the weekend when there is only one shift for the warehouse workers. RW_A1 and RW_A2 are slow moving material and the pallet space is often empty. Thus the Stage In areas operate with a periodic base stock inventory control policy with the base stock level B equal to the number of pallet spaces for each raw material. The Kanban layout for Product B is similar in PF1 and PF2. As the PF1 is shared by both Products A and B, the Kanban layout alternates with each production campaign.

The receiving of finished goods from the Stage Out areas to the warehouse also operates with a periodic review control policy. Twice a day (morning and afternoon) the warehouse workers go to the Stage Out area to check the readiness of any finished goods. They move all the finished goods from the Stage Out areas to the warehouse.

2.3 Number of Movements and Variation in 2007

Table 3 shows an example of a movement transaction in the internal database which record movements for both raw materials and finished goods along the spine. Item_Descrip describes the full name of the item. Quantity is the quantity of the item which is in the units of kilograms or tablets. From and To record the source and the destination of the movement respectively. Lot_# is the unique number of the lot from which a group of raw materials were produced by the supplier. Raw materials from the same lot are to be used together in production to ensure the quality. User is the worker who performed the movement and the timing information is recorded in Date and Time columns.

Table 3 Example of a movement transaction in the internal database

Item_Descrip	Quantity	From	To	Lot_#	User	Date	Time
PRODUCT A	1,250.00	02OUT	WXXX	AXXX	YIZHE	5/2/2007	9:26:50

Based on the internal database, there were 14,850 total movements performed by the warehouse workers in 2007, 53% of which come from the movements along the spine and the other 47% come from the movements outside the spine. We show in Figure 6 a histogram of the daily movements outside the spine.

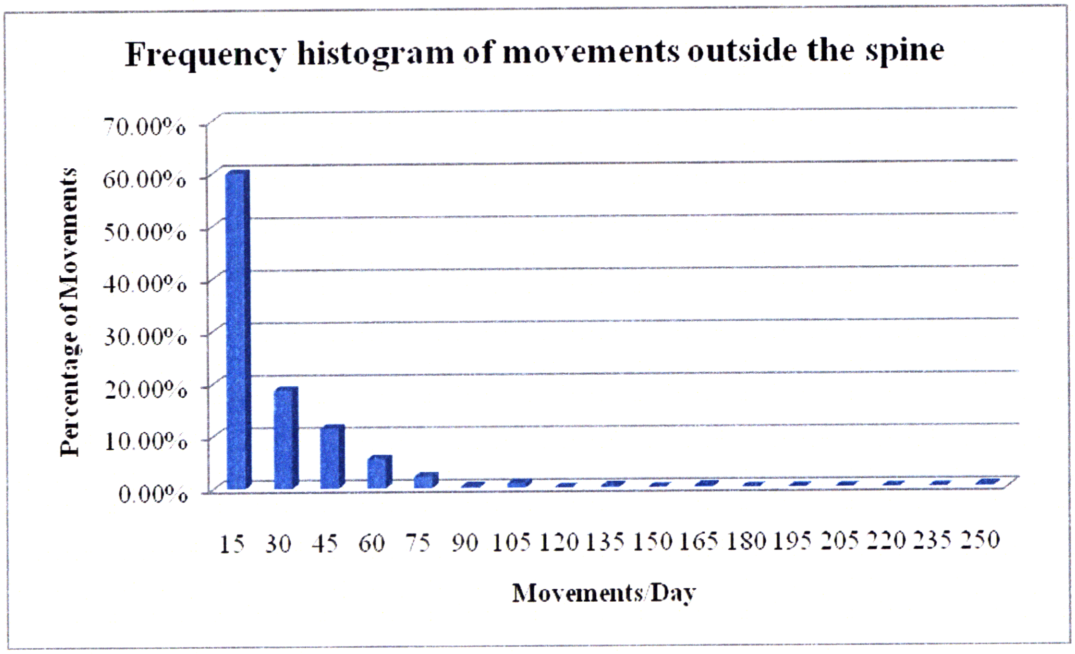

Figure 6 Frequency histogram of movements outside the spine

The movements outside the spine consist of sending raw materials to the shipping dock, picking up raw materials from outside the warehouse (combined 97%) and the internal movements within the warehouse (3%). As shown in Figure 6, the number of daily movements outside the spine seems to follow an exponential form with the daily average of 18 movements/day. Therefore the daily number of movements is concentrated around the average. Movements both outside and along the spine are performed by the same warehouse workers. Hence the time spent on movement outside the spine needs to be considered when estimating the capacity of movements along the spine.

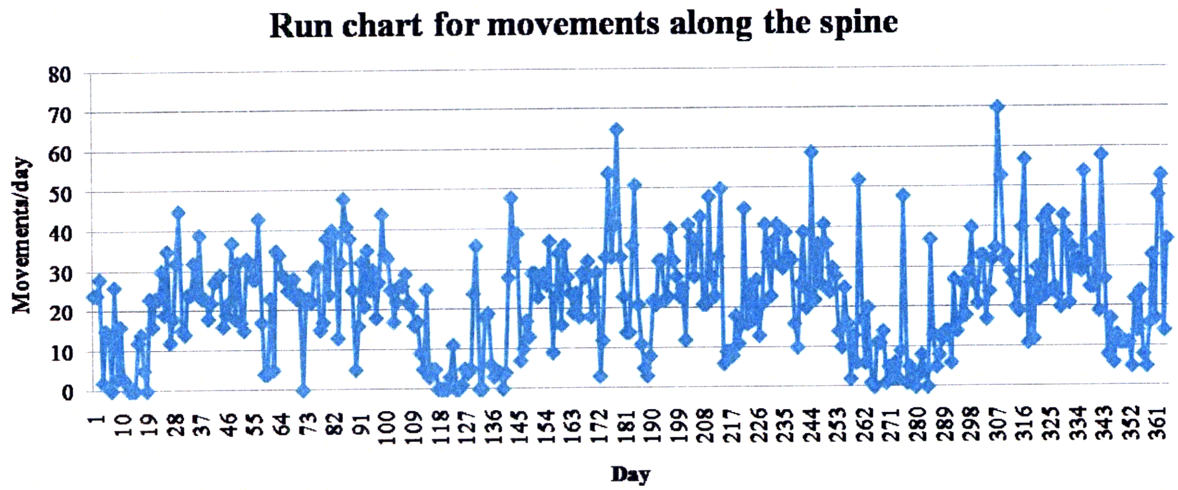

Figure 7 Run chart for movements along the spine in 2007

Figure 7 shows the number for daily movements along the spine by day in 2007. There is fluctuation in the daily movements which is mainly caused by production volume variation and further suggested by the frequency histogram in Figure 8. The movements along the spine in 2007 have a mean of 21.95 movements/day; the distribution appears to be a superposition of an exponential distribution and a normal distribution. The equal spread around the mean suggests a normal variation in movements. However there is also high percentage of days with a small number of daily movements. This is due to the small movements in production trials, change of campaigns and product re-inspection.

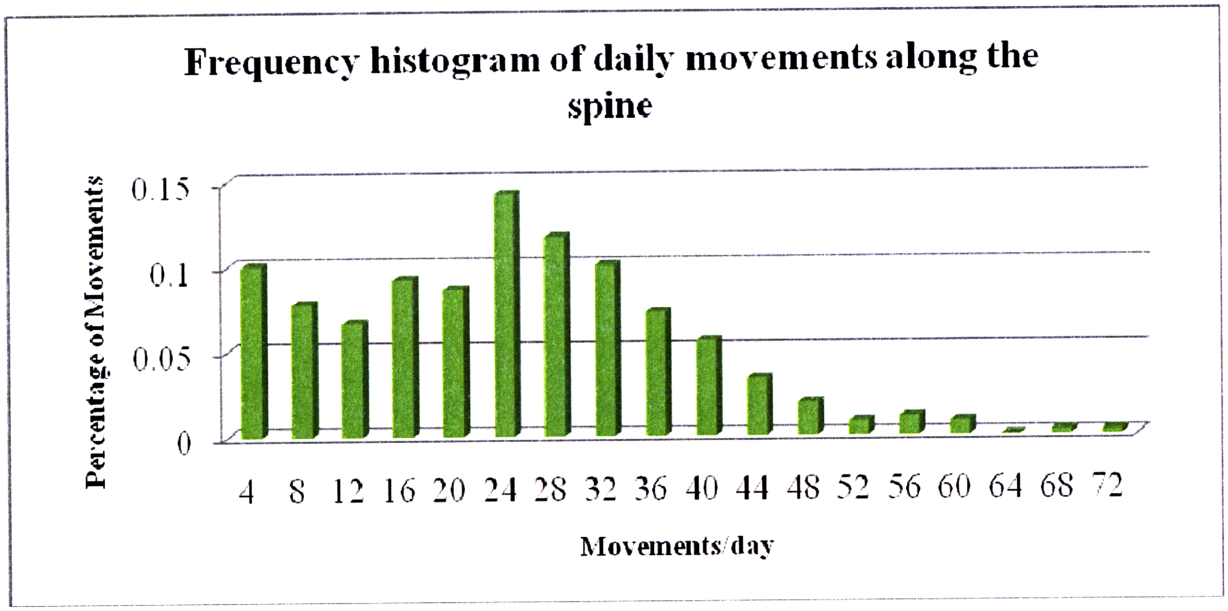

Figure 8 Frequency histogram of daily movements along the spine

Figure 9 shows the variation in the number of movements over the hours of a day. The warehouse workers work 2 shifts/day in the weekdays and 1 shift/day in the weekend. The first shift begins at 7:30 am and ends at 3:30 pm. The second shift ends at 11:30 pm. As suggested by Figure 9, most movements are performed in the early morning. This is because the production runs 24 hours/day and the raw materials need to be moved to feed the production and the finished goods need to be cleared out as the first task when the warehouse workers begin their daily work. There is rarely any movement during lunch and dinner break.

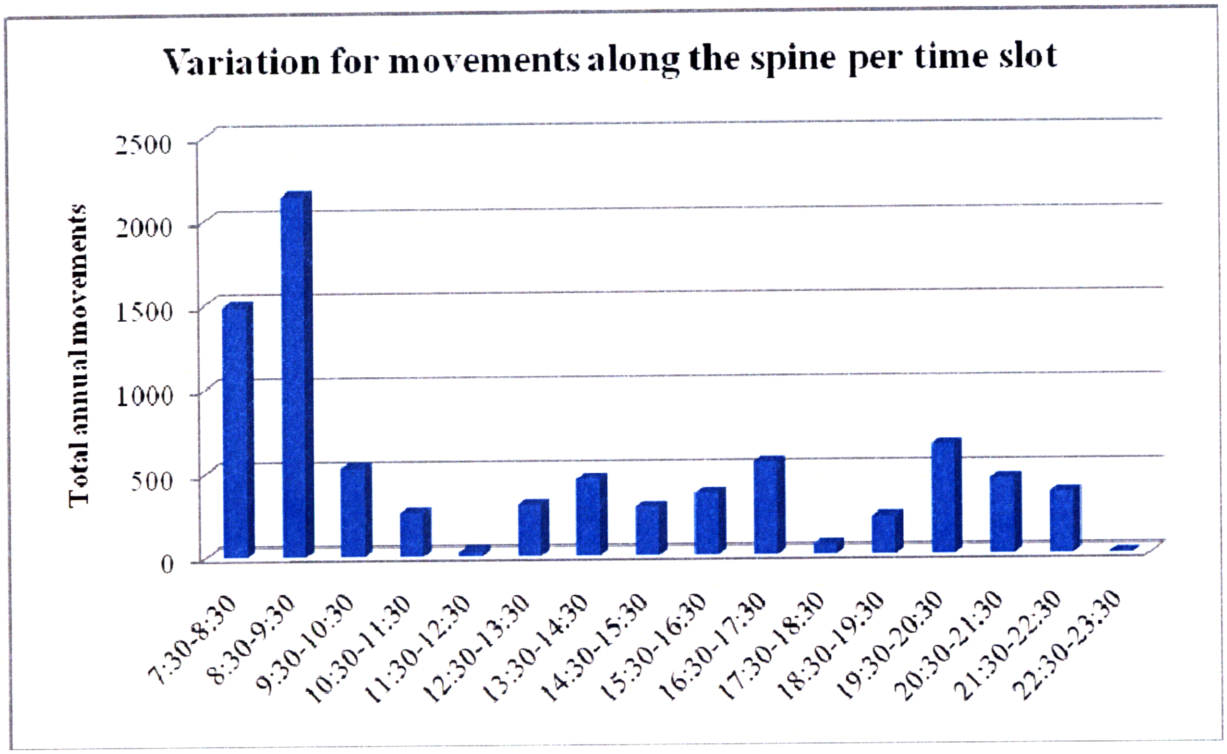

Figure 9 Variation of movements along the spine per time slot

2.4 Problem and Opportunities

The problem lies in the capability of the material handling and the total cost. There are two opportunities in solving this problem. Firstly more movements can be handled within the same period. This can be achieved by eliminating unnecessary movements, improving the speed of movements or obtaining more capacity. Secondly cost savings can be obtained with the right technology. A tradeoff between reduction in labors and increase in technology acquisition cost needs to be considered in order to choose the right material handing technology. The general approach will be discussed in Section 4.

3 Literature Review

This section describes the theoretical background that is relevant to the thesis study. A general concept about automation in material handling and an approach of selecting the automation technologies are discussed in Section 3.1. The periodic inventory model and the M/M/k queuing model are introduced in Section 3.2.

3.1 Automation Technologies in Material Handing

The function of an automation system can be described in general in Figure 10 [2]. The technical process refers to the material handing activity within a system where material is moved from one point to another. Principally the automation of any process requires target values which determine how materials are handled. This includes the path of travelling, loading and unloading locations, interaction with surrounding environment and communication with the control system. The function of an automation system often depends on the process status. Thus, information about the process status is recorded with sensors and evaluated in the form of signals. The process status includes the readiness of loading and unloading and traffic in material handling. The actuators at the end of the automation system convert the output signals into material handling parameters so that the process is influenced as desired.

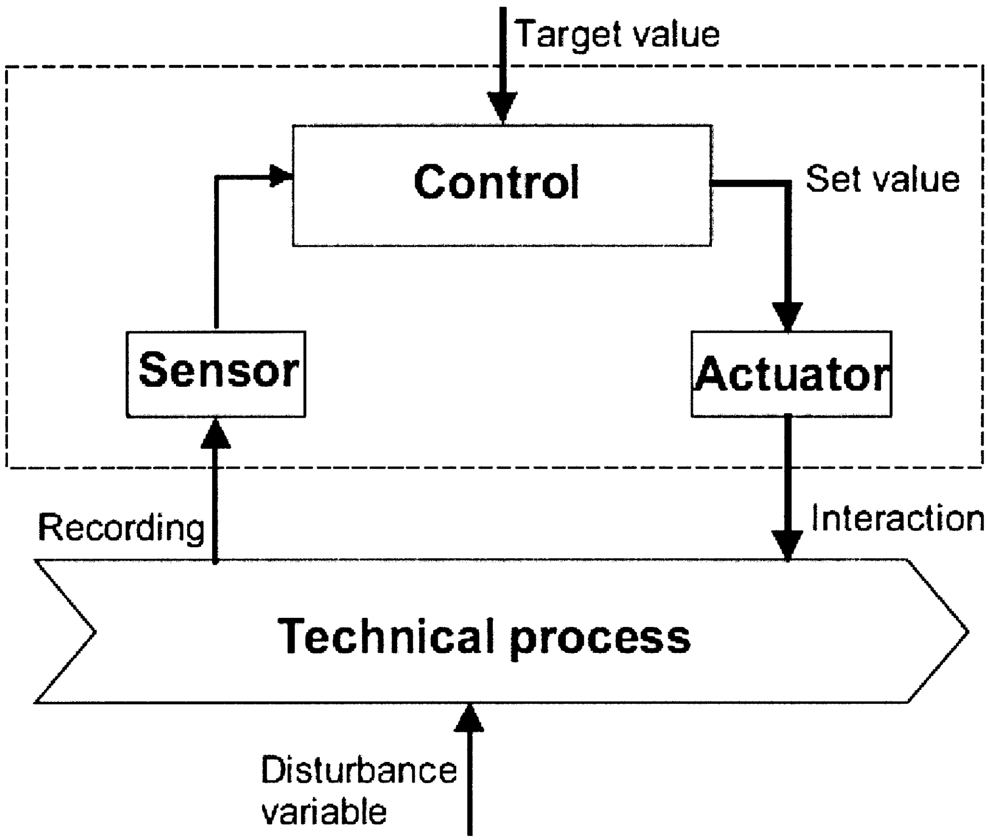

Figure 10 Active Principle of Automation [2]

Figure 11 lists the various types of material handling technologies. They can be broadly classified based on the movements handled per hour and the distance travelled. A manual pallet jack could be the solution to material handling if both the movements/hour and the distance travelled are small. A motorized forklift truck can handle moderate number of movements. A pallet conveyor is adopted when there is large number of movements but the distance is limited for the conveyor. A rail system such as a transfer car is installed when the distance is longer. Both the transfer car and the pallet conveyor run on the fixed path. An AGV can travel for even longer distance and has more flexibility. However it also comes with higher cost. A road vehicle is typically used when the materials are handled in an outdoor environment and the traveling distance is long.

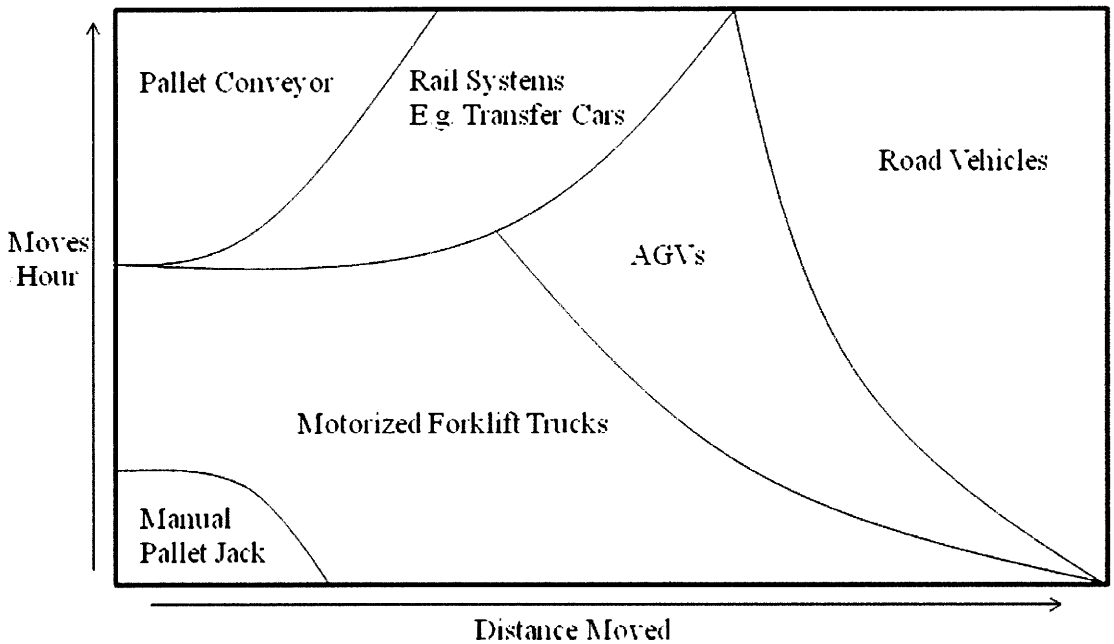

Figure 11 Approach to select material handling technologies [3]

3.2 Inventory Model and Queuing Model

The Stage In area has a base stock inventory model as shown in Figure 12. B is the base stock level which equals the number of pallet space allocated to each raw material. r is the review period. Currently the inventory in the Stage In areas is reviewed three times a day. L is the lead time that it takes the forklift trucks to replenish the pallet space [4].

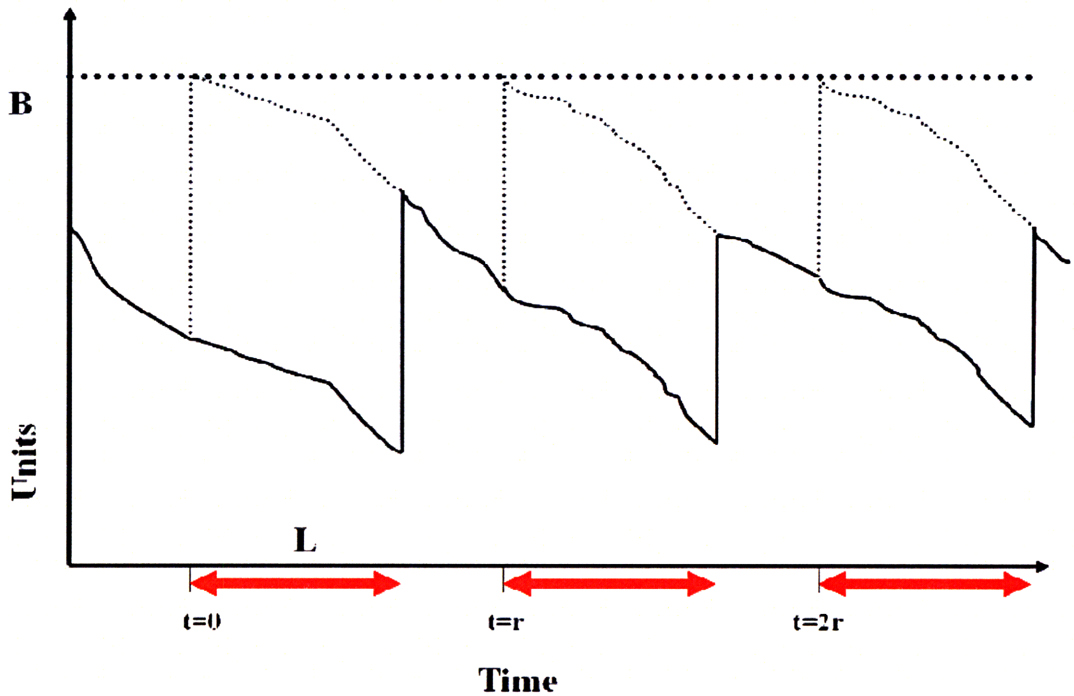

Figure 12 Periodic base stock inventory model [4]

The staging area can also be perceived as a queuing model. We can consider a movement request generated by production as a customer arrival to a queue. The forklift trucks are the servers that service the movement requests. Under an M/M/k system, both the inter-arrival time and service time are exponentially distributed. There are k concurrent servers in the system. k has a current value of 3, as we have three forklift trucks. The equations [5] are shown below and the symbol notation is shown in Table 4. The equations will be used in calculations of the queuing model in Section 6.1.

Utilization rate $\rho = \lambda/(k\mu)$ (1)

$$Q = \frac{k^k \rho^{k+1}}{k!(1-\rho)^2}\Pi_0 \tag{2}$$

$$\Pi_0 = \left\{\sum_{n=0}^{k-1}\frac{(k\rho)^n}{n!} + \frac{(k\rho)^k}{k!}\frac{1}{1-\rho}\right\}^{-1} \tag{3}$$

$$L = Q + k\rho \tag{4}$$

$$D = Q/\lambda \tag{5}$$

$$W = D + 1/\mu \tag{6}$$

Table 4 Symbol notation for queuing models in the staging area

Symbol	Notation
λ	Arrival rate of movement requests
μ	Service rate of movements by one forklift truck
k	Number of forklift trucks
ρ	Utilization rate
Q	Average queue length
D	Average queuing time before being served by the forklift truck
L	Average queue length in the system
W	Average time spent in the system

4 Method

There were three steps taken to further analyze the problem. The first step in problem diagnosis was to establish the capacity utilization for the movements along the spine. Manual time recording was performed to estimate the time taken per movement. Having obtained the number of movements in 2007, the daily time spent for movements along the spine can then be calculated by using the equation below.

$$Total\ Time / Day = Time\ Taken\ Per\ Movement \times Total\ Number\ of\ Movements / Day \tag{7}$$

The working hours and number of labors for the warehouse workers working along the spine are also known. Thus the capacity utilization for base year 2007 can be calculated as below.

$$Capacity\ Utilization = (Total\ Time / Day) / [(Shifts / Day) \times (Workers / Shift) \times (Hours / Worker)] \tag{8}$$

Secondly the utilization was forecasted for the future years in order to understand when there might be a problem with the capacity. The movements for each product are assumed to grow proportionally with the production volume. Given the number of movements and production batches in the base year 2007, movements per batch can be calculated.

$$Movements / Batch = Total\ Number\ of\ Movements / Number\ of\ Batches\ Produced \tag{9}$$

Movements/batch is assumed to be constant for all the products for the future years, as the production process is assumed to remain stable. Hence the total movements in a future year can be obtained from the following equation.

$$Total\ Movements = \sum_{Product\ A}^{All\ products} [(Movements / Batch) \times Number\ of\ Batches\ Produced] \tag{10}$$

The capacity utilization can thus be forecasted and the problem will be revealed when the utilization exceeds the utilization cap. The utilization cap is defined as the level of capacity utilization beyond which the performance of material handling is not desirable. The acceptable utilization cap is determined in Section 5.4.

The next step of the problem diagnosis is to establish the problem consequences and define the drivers to the problem. The most effective solution can only be found after understanding which segment of the material movement is the most time-consuming and has the largest opportunity for improvement.

The final stage of the thesis is to investigate solutions to the problem. Five solutions were explored, each addressing a respective driver to the problem: install more forklift trucks; redesign the Kanban layout in the staging areas; automate the staging areas with conveyors; automate the transportation using transfer cars; automate the transportation using AGVs. A cost and benefit analysis was performed to assess the operational effectiveness of each solution. The return of investment (ROI) was estimated for the solutions via internal rate of returns (IRR). Lastly the best solution with the most operational and cost advantage was recommended.

5 Problem Diagnosis

5.1 Manual Time Recording

Time recording was done to estimate the time taken per movement along the spine. Two directions of movements were measured—movements of finished goods from Stage Out to the warehouse and movements of raw materials from the warehouse to Stage In as shown in Table 5 and Table 6.

Table 5 Time recording for movements of finished goods from Stage Out to Warehouse

Movement Step	Time Segment	Time Estimate (mins)
Travel from warehouse to staging	Transportation	0.25
Travel from staging to Stage Out	Transportation	0.17
Space adjustment in Stage Out	Space adjustment	4.00
Move items from Stage Out to staging	Transportation	0.96
Finished goods check	Checking	2.48
Strapping	Strapping	0.72
Carry items from staging to warehouse	Other coordination	0.90
Scan pallet barcode to finish	Interaction with control system	0.65
Inter-step motion		1.01
	Total Time	11.14

Table 6 Time recording for movements of raw materials from warehouse to Stage In

Movement Step	Time Segment	Time Estimate (mins)
Create movement queue in the system	Interaction with control system	0.08
Access information from barcode device	Interaction with control system	4.06
Move items down from the rack in warehouse	Other coordination	1.42
Carry items from warehouse to staging	Transportation	1.08
Space adjustment in Stage In	Space adjustment	4.00
Carry items from staging to Stage In	Transportation	1.00
Inter-step motion		1.16
	Total Time	12.80

Each movement was broken down into several movement steps and the time taken for each step was repeatedly measured for nine times each. The mean of the measures was taken as a point estimate for each movement step and the sum of all steps was calculated for the total time taken per movement.

To further verify the accuracy of the time estimate per movement, we looked into the internal database which records the entry time for each movement. An example of the transportation time calculation for the raw materials is illustrated in Table 7. The three forklift truck drivers were working together and this worker, TAYCH is in charge of moving the pallet down from the rack in the warehouse, transporting it to staging outside Stage In and carrying it to the allocated pallet space in Stage In. The time entered into the database is the starting time of moving the pallet down from the rack. Thus the difference between the neighboring entries is the time taken for the three movement steps. As shown in the illustration, the time taken for the three steps was 3.5 minutes. We were able to compare nearly 200 such observations from the database; the mean is 3.65 minutes. According to the time estimate in Table 6, the three steps are estimated to take 3.5 minutes. Hence, based on the comparison we are confident that our time estimate is relatively accurate and conservative.

Table 7 Illustration of transportation time calculation through the Database

Item description	From	To	User	Date	Time	Δ
RW_A2	WXXXX	02IN	YIZHE	4/11/2007	8:37:24	
RW_A2	WXXXX	02IN	YIZHE	4/11/2007	8:40:55	0:03:31

The movement of finished goods begins with the forklift truck travelling from the warehouse to the staging area which is a temporary storage place just outside the Stage Out area. The forklift truck then drives into the Stage Out area and the driver gets off the truck for space adjustment, which typically involves moving pallets into the correct pallet space in Stage Out and clearing paths for the pallets to be moved out of Stage Out. The next step is to carry the items from Stage Out to the staging area using the forklift truck. The staging area is then used as a centralized area where checking and strapping are performed. Checking ensures the correct pallets to be picked up and the sealing of drums. Strapping follows the checking step by wrapping the drums on each pallet with plastic tapes. Once strapping is finished, the pallet is moved to the correct rack in the warehouse. The movement is completed by scanning the pallet's barcode using the barcode device, which informs the control system that the movement is completed as per instruction. An additional 10% of time is added to the total time for the inter-step motions which include the time taken for movements and other motions between the neighboring steps.

The movement of raw materials is similar to finished goods except for three differences. Firstly the movement direction is from the warehouse to the Stage In areas. Secondly the movement begins with creating a movement queue in the control system via a computer program in the warehouse office. The system receives information on number, types and destinations of raw materials to be moved. It then chooses the optimized locations of pallets to be picked from the warehouse. The location information for the pallets is then retrieved by the worker via the barcode device. Lastly the pallet's barcode has been scanned in the beginning of the movement and does not need to be scanned again at the end of the movement.

5.2 Capacity Utilization

There are four forklift truck drivers in the warehouse. Three of them are dedicated to the movements along the spine and the other one is in charge of the movements outside the spine. The movements outside the spine generally take less time per movement compared with the movement along the spine. This thesis is also only focused on the material movements along the spine. Thus the capacity utilization analysis is only on the movements along the spine based on the three dedicated forklift truck drivers.

The capacity utilization in year 2007 was calculated as the base year for utilization forecasting. According to the internal data base, there are 21.95 movements per day along the spine. The time taken per movement of raw materials is used as the best case scenario and the time taken per movement of finished goods is used as the worst case scenario. The two scenarios suggest a variation in total time spent on movements per day, thus a variation in utilization. The variation is due to the difference in types of movements and gives more precise estimate on when the capacity problem would occur. The time taken per day is calculated as below.

$$Total\ Time\ /\ Day\ (best) = 11.14 \times 21.95 \div 60 = 4.077(hrs)$$

$$Total\ Time\ /\ Day\ (worst) = 12.80 \times 21.95 \div 60 = 4.685(hrs)$$

Besides the material movement time as shown above, there are two more segments of time for the forklift drivers—human flow and waste flow. Human flow refers to the travelling of the workers on foot to Stage Out for availability of finished goods to be picked up and to warehouse for availability of empty pallet spaces to move the raw materials to. Waste flow refers to the movements of production wastes from Stage Out to the waste dock. Both human flow and waste flow take 1—1.5 hours/day. The time segments for the three types of flows are summarized in Table 8.

Table 8 Time taken per day for the three types of flows

Time Segment	Duration (best) (hours/day)	Duration (worst) (hours/day)
Human	1	1.5
Material	4.077	4.685
Waste	1	1.5
Total	6.077	7.685

There are three dedicated forklift drivers for movements along the spine at every shift. There are two shifts per day and eight hours per shift. 6.5 effective hours are spent on movements per shift after deducting the break time. Hence the total available hours per day and the capacity utilization in 2007 are calculated below.

$$Total\ Available\ Hours = 6.5 \times 2 \times 3 = 39(hrs)$$

$$Capacity\ Utilization\ (best) = 6.077 / 39 = 15.6\%$$

$$Capacity\ Utilization\ (worst) = 7.685 / 39 = 19.7\%$$

The capacity of the current labors and technology on movements along the spine was utilized at 15.6% to 19.7% in year 2007.

5.3 Utilization Forecast

Utilization forecast is done based on the long-term production plan by assuming that the number of movements for each product will grow proportionally with the number of batches produced. Thus number of movements per batch of product needs to be calculated first in order to perform the forecast. The movement breakdown per raw material, finished good and packaging material is listed in Table 9 for Product B1 and in Table 10 for Product A-7. 23 batches of Product B1 and 479 batches of Product A-7 were produced in year 2007. The number of movements per batch for Product B2 is assumed to be the same as Product B1 and the number of movements per batch for Product C is the assumed to be the same as Product A-7.

Table 9 Movement breakdown per batch of production for Product B1 in 2007

Items	**Number of Movements**
Product B1	54
RW_B1	106
RW_B2	58
RW_B3	13
RW_Comm1	3
RW_Comm2	14
RW_B4	29
RW_Comm3	6
RW_B5	32
Other Raw Materials	87
Packaging	62
Total Movements	464

Table 10 Movement breakdown per batch of production for Product A-7 in 2007

Items	**Number of Movements**
Product A-7	1755
RW_A1	8
RW_A2	6
RW_A3	14
RW_A4	497
RW_A5	63
RW_A6	561
RW_A7	281
RW_Comm1	61
RW_Comm2	112
RW_Comm3	54
Other Raw Materials	12
Packaging	406
Total Movements	3829

Table 11 Number of movements per batch of production for each product

	Product A-7	Product B1	Product B2	Product C
Movements/batch	7.993	20.185	20.185	7.993

The number of movements per batch for each product is shown in Table 11, which is assumed to be constant for all the products for the future years, as the production process is assumed to remain the same. Product A-7 and Product A-9 are the exact same in material handling and production process except the different product quantity per batch. Thus all the batches produced for Product A-9 were converted into Product A-7 with a converting ratio of 9/7 in the forecast. As shown in Table 12, the total movements will grow by about 9 times by year 2016.

Table 12 Forecasted total number of movements

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Total Movements	7859	12802	16959	25254	32765	42178	50922	60292	69304	76081

There are three segments of time spent on the movements along the spine—human flow, material flow and waste flow. The total time spent on material flow and waste flow is assumed to grow proportionally with the total number of movements. Human flow on the other hand is assumed to take the same amount of time in the future. The total available hours also remain the same with the current material handling.

As shown in the capacity utilization forecast in Table 13, the capacity utilization will exceed 100% by 2014 in the best case and by 2013 in the worst case. When the utilization exceeds 100%, it indicates that the movements on average cannot be completed within the same day. However the forecasted utilization only measures the average time spent on movements. The variability of the daily movements needs to be considered in order to determine the capacity utilization cap, under which the capacity of material handling is acceptable.

Table 13 Capacity utilization forecast

Best Case	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Human (hrs)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Material (hrs)	4.08	6.64	8.80	13.10	17.00	21.88	26.42	31.28	35.95	39.47
Waste (hrs)	1.00	1.63	2.16	3.21	4.17	5.37	6.48	7.67	8.82	9.68
Total (hrs)	6.08	9.27	11.96	17.31	22.17	28.25	33.90	39.95	45.77	50.15
Utilization	15.6%	23.8%	30.7%	44.4%	56.8%	72.4%	86.9%	102.4%	117.4%	128.6%
Worst Case										
Human (hrs)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Material (hrs)	4.68	7.63	10.11	15.05	19.53	25.14	30.35	35.94	41.31	45.35
Waste (hrs)	1.50	2.44	3.24	4.82	6.25	8.05	9.72	11.51	13.23	14.52
Total (hrs)	7.68	11.57	14.85	21.37	27.28	34.69	41.57	48.95	56.04	61.37
Utilization	19.7%	29.7%	38.1%	54.8%	70.0%	89.0%	106.6%	125.5%	143.7%	157.4%

5.4 Utilization Cap

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 14 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 14 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.

$$Q = Average(Q1) \tag{11}$$

$$Q\% = Q / u' (12) \tag{12}$$

$$Max\ Q = Maximum(Q1) \tag{13}$$

$$Max\ Q\% = Max\ Q / u' \tag{14}$$

$$W = Q / u' \tag{15}$$

The queuing model was tested at five possible capacity utilization levels—60%, 65%, 70% 75% and 80%. As shown in Table 15, 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 15 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.

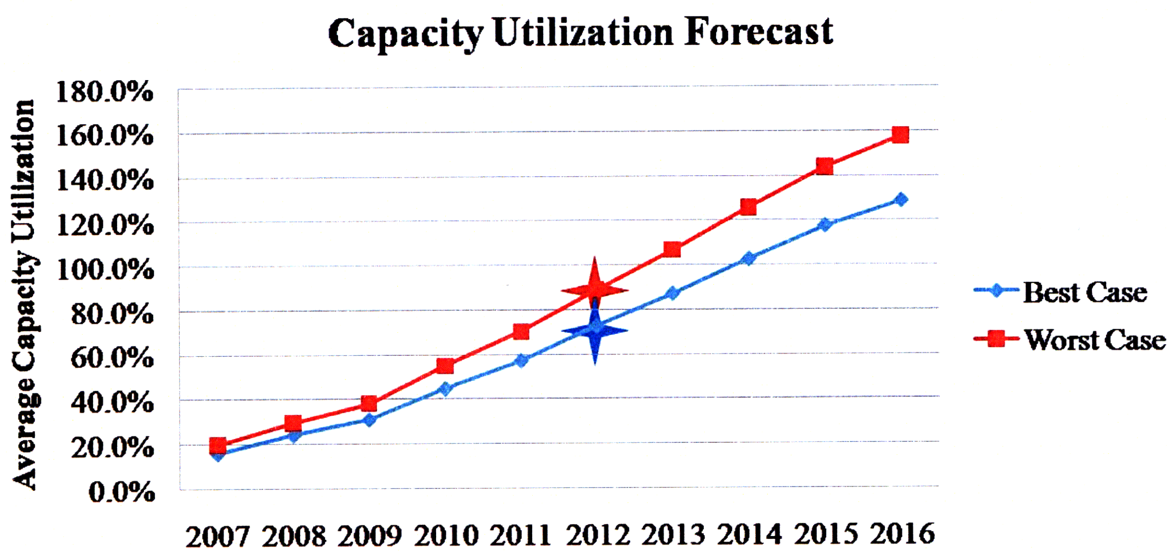

Figure 13 Capacity utilization forecast

As shown in Figure 13, 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.

5.5 Queuing Model to Verify the Accommodation to Utilization Variability

The daily capacity utilization fluctuates as the daily number of movements varies. The staging areas hold inventory that is reviewed periodically. There is a possibility that the number of pallets waiting to be moved exceeds the allocated pallet space or the waiting time exceeds the desired period. Usually the materials are required to be moved within the same day. Thus a simple queuing model is adopted to verify whether the total pallet spaces are enough to accommodate the utilization variation.

An M/M/K queuing model is used in the analysis of the staging inventories under the current material handling. The parameters are calculated below by using the equations in Section 3.2.

$$k = 3 \ \textit{forklift drivers}$$

$$u = 1/(\textit{hours} / \textit{movement}) = 1/(12.804/60) = 4.69 \ \textit{movements} / \textit{hour}$$

$$\lambda = (\textit{movements} / \textit{day}) \times (\textit{days} / \textit{year}) / (\textit{hours} / \textit{year}) = 22.48 \times 358 / 4936 = 1.63 \ \textit{movements} / \textit{hour}$$

μ is the service rate by one forklift driver. λ is the arrival rate of movement requests. λ is assumed to grow proportionally with the total number of movements. Q and W are the two important output parameters to be monitored in the queuing model. Q refers to the average number of pallets waiting in the staging areas to be moved. W is the total time spent from when a movement request is initiated until the movement is completed. As shown in Table 16, both the average number of waiting pallets and the waiting time remain almost the same for the first few years and grow rapidly around year 2016. Figure 14 further illustrates the sharp increase between 2014 and 2016.

Table 16 Results from the M/M/K queuing model in Staging

Year	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
λ (Moves /hour)	1.63	2.43	3.22	4.71	6.02	7.66	9.21	10.88	12.49	13.76
Q (Pallets)	0.0007	0.0035	0.0105	0.0463	0.1245	0.3434	0.8147	2.0693	6.3654	44.486
W (Hours)	0.214	0.215	0.217	0.223	0.234	0.258	0.302	0.404	0.723	3.446
Total Moves	5959	8884	11787	17209	22022	27996	33678	39767	45674	50308

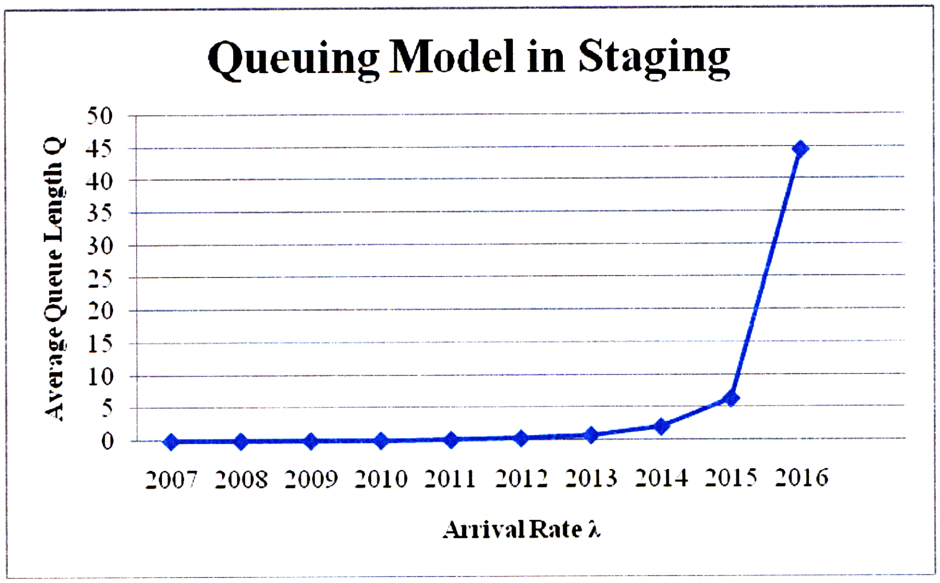

Figure 14 Queuing model in the Staging areas

The average number of pallets waiting in the staging areas remains small until it goes up exponentially before year 2016. This is because the utilization ($\rho = \lambda/\mu$) approaches 100% near year 2016. The waiting time is also acceptable before year 2016.

The capacity utilization forecast in Section 5.3 suggests the capacity utilization problem will occur around year 2012 and 2013. If we apply solutions in 2011—one year before the average utilization problem, the problem to accommodate the variation in 2016 can be easily avoided. Thus solutions will be implemented in 2011 and only the average capacity utilization needs to be used in evaluating solutions.

5.6 Problem Consequences and Definition of Drivers

The daily capacity utilization over 100% indicates that the movements required cannot be completed by the current labor force and technology. Some movements have to be postponed to the next day. There are two likely consequences with the over-utilized capacity. Firstly the lack of raw material supply may starve the production. Secondly the finished goods may not be moved out soon enough and thus it may block the production. Given that it is never desirable to stop the production due to starvation or blockage, temporary contract workers need to be hired and additional forklift trucks need to be rented to provide the additional capacity. The cost involved in hiring additional contract workers and renting forklift trucks was used in the ROI analysis to quantify the consequences of capacity over-utilization.

The time spent on raw material sending and finished goods receiving—the two major types of movements, is segmented in Figure 15 and Figure 16. The segmentation is based on Table 5 and Table 6.

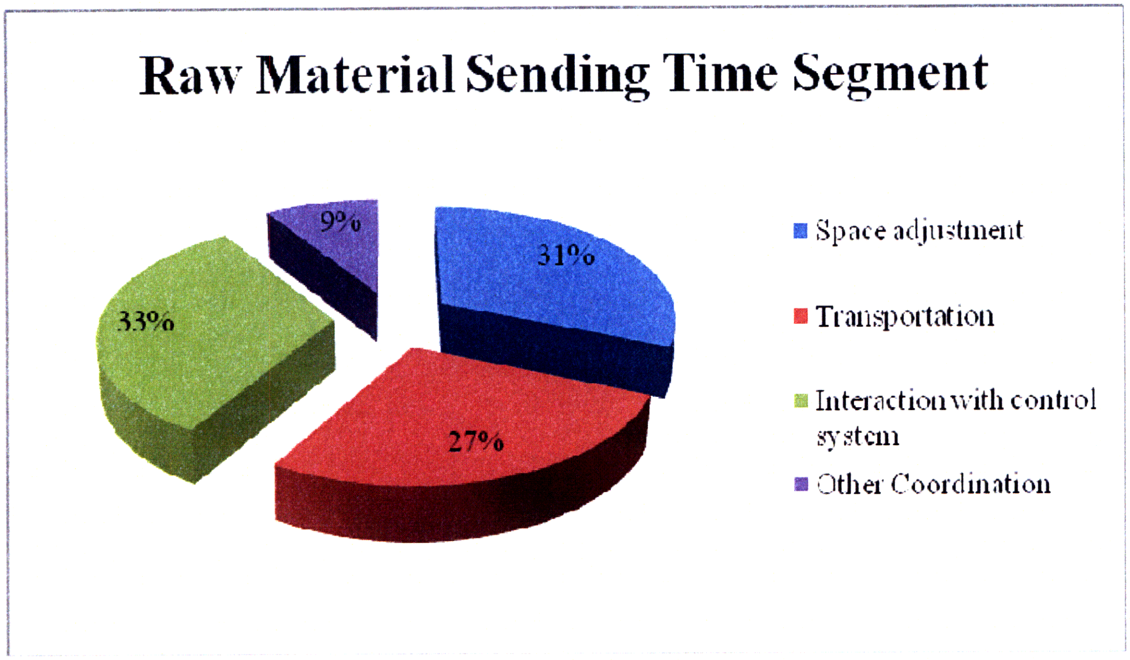

Figure 15 Time segmentation of raw material sending from warehouse to Stage In

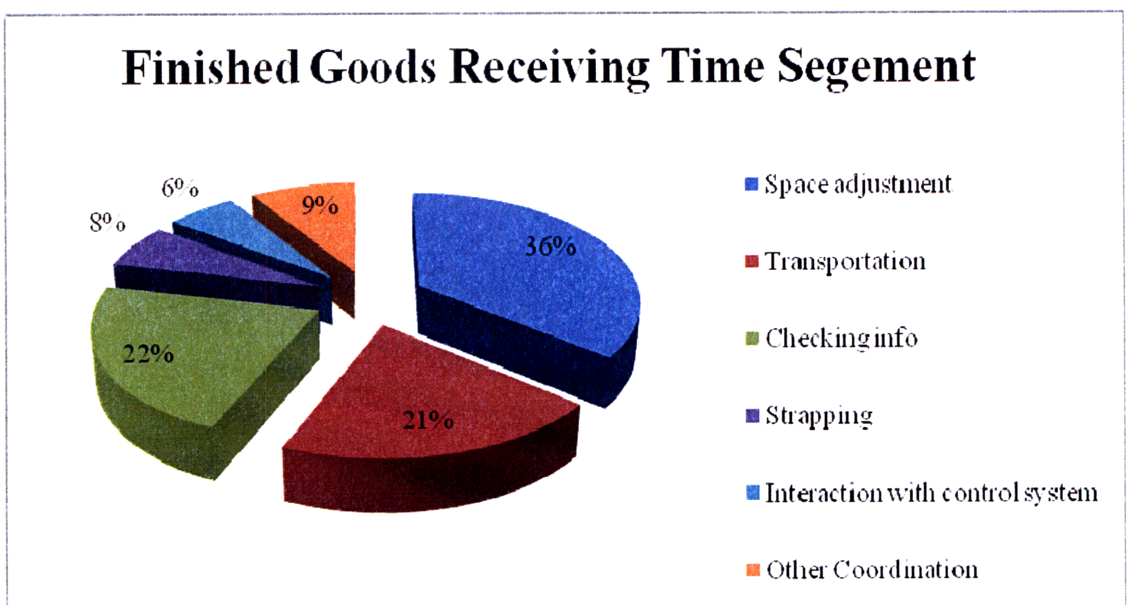

Figure 16 Time segmentation of finished goods receiving from Stage Out to warehouse

Transportation and space adjustment are the two most time-consuming segments. The combination of both contributes to about 50% of the time spent on the movement. Interaction with the control system and checking also takes much time in raw material sending and finished goods receiving respectively. However a change in the control system will involve a changeover of the Enterprise Resources Planning (ERP) system, which is not in the scope of the study. Checking has also to be performed as instructed as part of the quality assurance process. Hence solutions to reduce the time on transportation and space adjustment will be investigated.

6 Solution Investigation

There are two aspects in addressing the capacity problem. Firstly the time taken per movement can be reduced. This can be achieved by reducing the transportation and space adjustment time. Two automation technologies—AGVs and transfer cars were investigated to reduce the transportation time. AGV is a high investment solution with more functionality and more flexibility. A transfer car on the other hand provides a cheaper solution but with fixed path. Two other solutions were also investigated to reduce the time in space adjustment—Kanban redesign and automation in the staging area by conveyors. Secondly more material handling technologies can be added to increase the capacity itself, i.e. more forklift trucks can be purchased and more warehouse workers can be hired to increase the capacity of the existing material handling.

Only improvement on the material handling in the staging areas is discussed in the following sections. Firstly a qualitative analysis of the staging areas is performed to evaluate the improvement on material handling by redesigning the Kanban layout. Secondly we consider automation in the staging areas by installing conveyors in order to reduce the space adjustment time. In comparison we might purchase additional forklift trucks to achieve the same capacity objective as the conveyor solution. A financial analysis is performed to evaluate the more cost-effective solution between the two solutions. Automation technologies on transportation such as AGVs and transfer cars are analyzed in detail in Ms. Changhui Zhao's thesis study—"Strategic and Operational Plan for Better Material Handling" [1].

6.1 Redesign Kanban in Staging

Kanban refers to the position and the number of pallet spaces allocated to each raw material and finished product. There are five types of Kanban layouts in total—raw materials of Product A in PF1 Stage In, raw materials of Product B1 in PF1 Stage In, finished goods of Product A in PF1, raw materials of Product B1 in PF2 Stage In and finished goods of Product B1 in PF2 Stage Out. There is only one type of raw material of Product B1 stored in PF2 Stage In. There are eight pallet spaces reserved for this raw material. The position of pallet spaces in the Kanban layout for the two finished products is also not relevant, as there is only one type of finished products stored under each Kanban. There are 24 pallet spaces for each Kanban of the finished products. The Kanban layout of raw materials for Product A is shown in Figure 5 and the Kanban layout for Product B1 is shown in Figure 17. The pallet spaces in dash lines are only to be filled during the weekend.

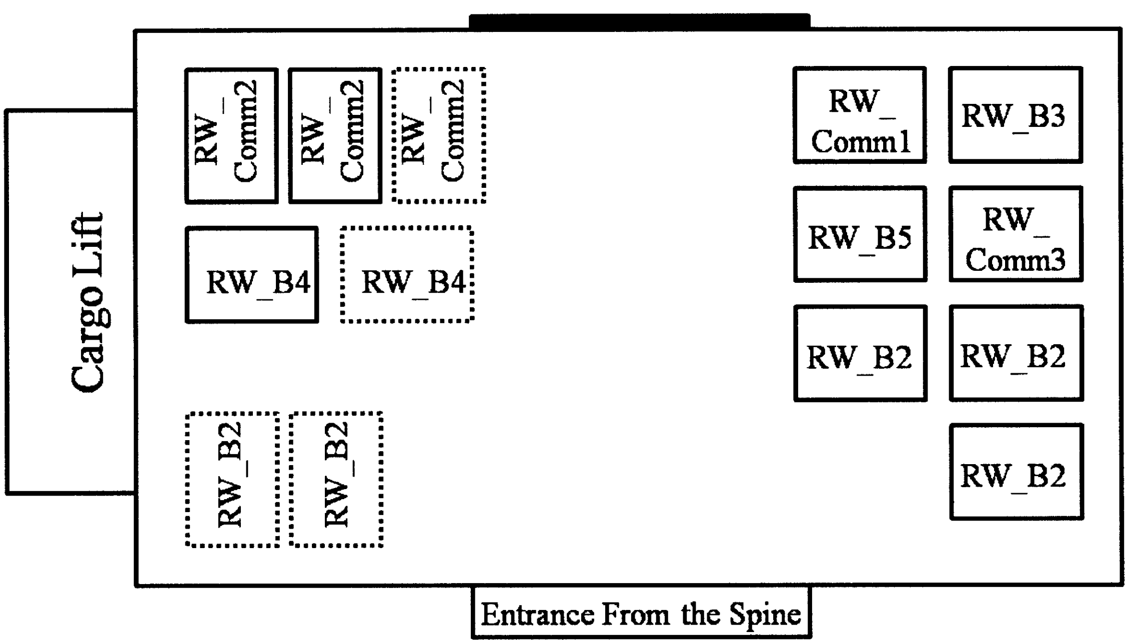

Figure 17 Kanban layout of raw materials of Product B1 in PF1 Stage In

The two Kanban for raw materials of Product A and Product B1 in PF1 Stage In can each take up to 17 pallet spaces. As shown in Table 17 for Product A and Table 18 for Product B1, the number of pallet spaces allocated to each raw material generally corresponds to its total number of movements along the spine. There is also only one shift daily for the warehouse workers in the weekend compared with two shifts daily in the weekdays. Hence more pallet spaces are added in the weekend to cover the round-the-clock production.

Table 17 Pallet spaces and number of movements for raw materials of Product A in PF1 Stage In in 2007

	Total Movements	Pallet Spaces (Weekday)	Pallet Spaces (Weekend)
RW_A6	972	4	6
RW_A4	858	3	3
RW_A7	498	2	2
RW_Comm2	208	1	1
RW_Comm1	100	1	1
RW_A5	92	1	1
RW_Comm3	84	1	1
RW_A3	17	1	1
RW_A1, RWA2	22	1	1
Total	2851	15	17

Table 18 Pallet spaces and number of movements for raw materials of Product B1 in PF1 Stage In in 2007

	Total Movements	Pallet Spaces (Weekday)	Pallet Spaces (Weekend)
RW_B2	30	3	5
RW_B4	21	1	2
RW_B5	15	1	1
RW_Comm2	13	2	3
RW_B3	7	1	1
RW_Comm1	3	1	1
RW_Comm3	1	1	1
Total	90	10	14

The objective of redesigning the Kanban layout is to minimize space adjustment time for each movement in PF1 Stage In and tolerate higher utilization of the material handling. There are three principles taken in the redesigning process. Firstly the space in Stage In is to be fully utilized for both products. Currently there are 15 pallet spaces for Product A in the weekdays and 17 pallet spaces in the weekends. This arrangement of pallets has fully utilized the space without obstructing the traveling of forklift trucks and people in the Stage In area. On the other hand, Product B1 has only 10 pallet spaces in the weekdays and 14 pallet spaces in the weekends. The numbers of pallet spaces are to be increased to 15 and 17 in the weekdays and weekends respectively. This is because higher number of pallet spaces corresponds to longer queuing length able to be accommodated. We can view the number of pallets waiting to be picked up in the staging areas as the queue length, L and the forklift truck driver as the server. The utilization of the server, ρ measures the capacity utilization of the forklift truck driver. According to Equation (16) in the M/M/1 queuing model, the longer queuing length, L guarantees a higher utilization, ρ. Thus we can theoretically afford to run at a higher capacity utilization, i.e. to handle more movements with the same number of forklift truck drivers.

$$L = \frac{\rho}{1-\rho} \tag{16}$$

Secondly the number of pallet spaces allocated to each raw material should correspond to the total number of movements. We can view the rate of the forklift truck drivers serving the movement requests as the service rate, u and the arrival rate of movement requests as the arrival rate of the queuing model, λ. According to Equation (17) in the M/M/1 queuing model, the queuing length, L corresponds to the arrival rate, λ. Thus the number of pallet spaces allocated to each raw material should correspond to its total number of movements. This is done to minimize the space adjustment time. In addition, raw materials within the same range of total movements are grouped together and the largest number of movements is taken to represent the group. The same number of pallet spaces is assigned to all the members of the group. The number of pallet spaces is determined to be as close to the group's representative number of movements.

$$L = \frac{\lambda}{\mu - \lambda} \tag{17}$$

Lastly the positions of the pallets are to be adjusted so that the same raw materials reside together. The raw materials with the most pallet spaces are also put next to the cargo lift which makes the transporting easier for these most frequently moved materials. The proposed pallet spaces for Product A and Product B1 are shown in Table 19 and Table 20 respectively. As shown in Figure 18 and Figure 19, the proposed Kanban layouts for the two products reflect the three Kanban redesign principles.

Table 19 Proposed pallet spaces for raw materials of Product A in PF1 Stage In

	Total Movements	Pallet Spaces (Weekday)	Pallet Spaces (Weekend)
RW_A6	972	4	5
RW_A4	858	3	4
RW_A7	498	2	2
RW_Comm2	208	1	1
RW_Comm1	100	1	1
RW_A5	92	1	1
RW_Comm3	84	1	1
RW_A3	17	1	1
RW_A1, RWA2	22	1	1
Total	2851	15	17

Table 20 Proposed pallet spaces for raw materials of Product B1 in PF1 Stage In

	Total Movements	Pallet Spaces (Weekday)	Pallet Spaces (Weekend)
RW_B2	30	4	5
RW_B4	21	3	4
RW_B5	15	3	3
RW_Comm2	13	2	2
RW_B3	7	1	1
RW_Comm1	3	1	1
RW_Comm3	1	1	1
Total	90	15	17

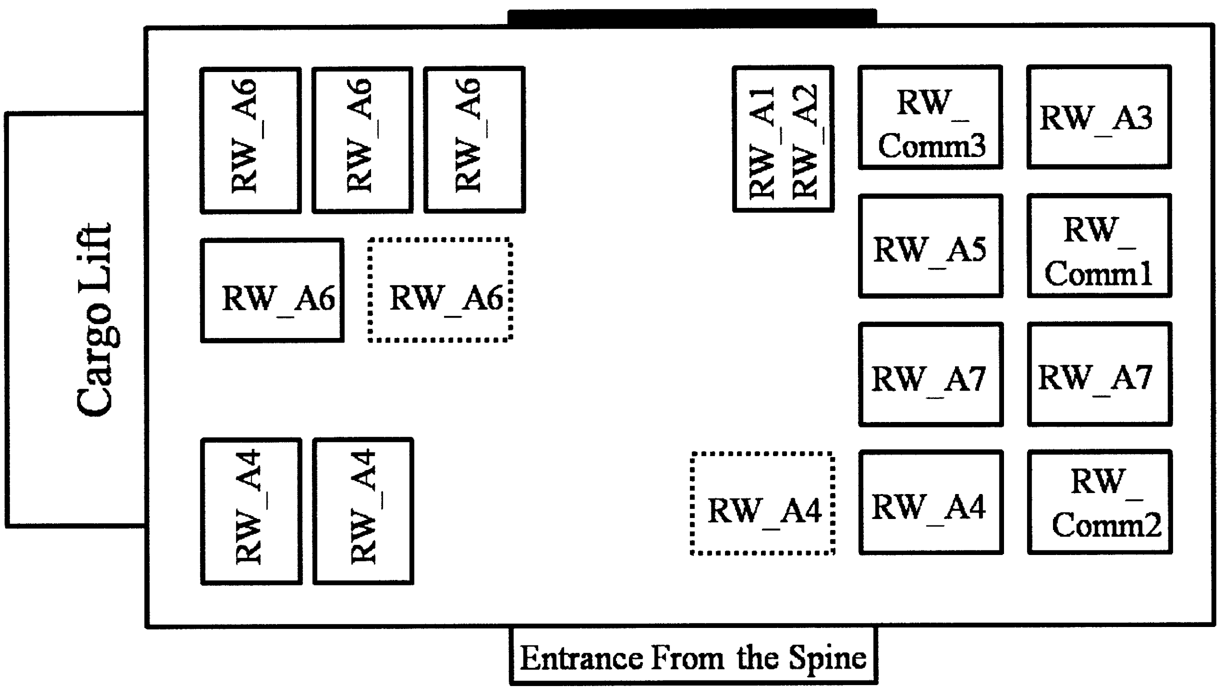

Figure 18 Proposed Kanban layout for the raw materials of Product A in PF1 Stage In

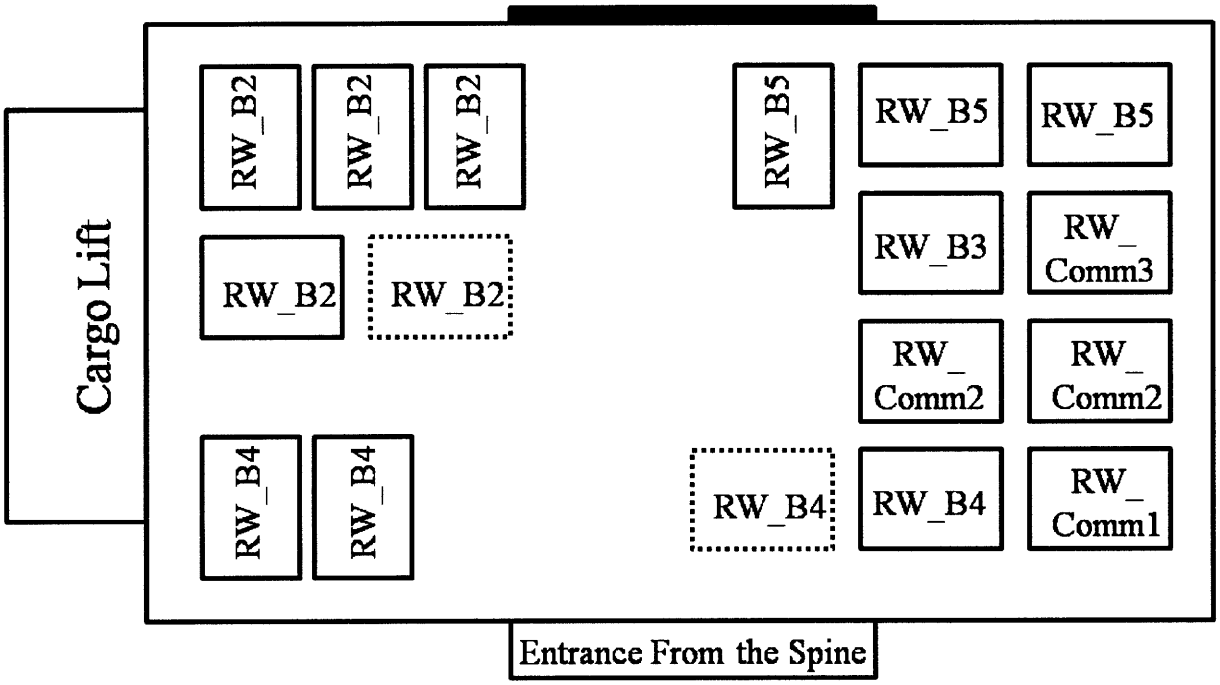

Figure 19 Proposed Kanban layout for the raw materials of Product B1 in PF1 Stage In

The proposed Kanban layouts give two benefits. Firstly some space adjustment time can be saved with the proposed Kanban layouts, as the pallet spaces are balanced to reflect the number of movements for each raw material. The same type of raw materials is also stored together for ease of retrieval. Secondly the space in the staging areas is fully utilized. More pallet spaces are added for Product B1 which theoretically makes it possible to run the material movements at higher capacity utilization.

6.2 Automate Staging by Conveyors

The conveyors are to be installed in the staging areas in order to reduce the space adjustment time. The major cause of space adjustment is the enforcement the first-in-first-out (FIFO) rule for the pallets of materials. The conveyor automates the movements within the staging areas. There are sensors installed on the conveyor which detects the location of the pallets. When an item is requested by either the production or the warehouse workers, the conveyor can unload the respective pallet based on the FIFO rule.

As shown in Figure 20, the proposed conveyor in Stage In has a circle shape to facilitate the movements for the various types of raw materials. The conveyor in Stage Out has a curved line shape as there is only one type of finished goods to be moved in Stage Out.

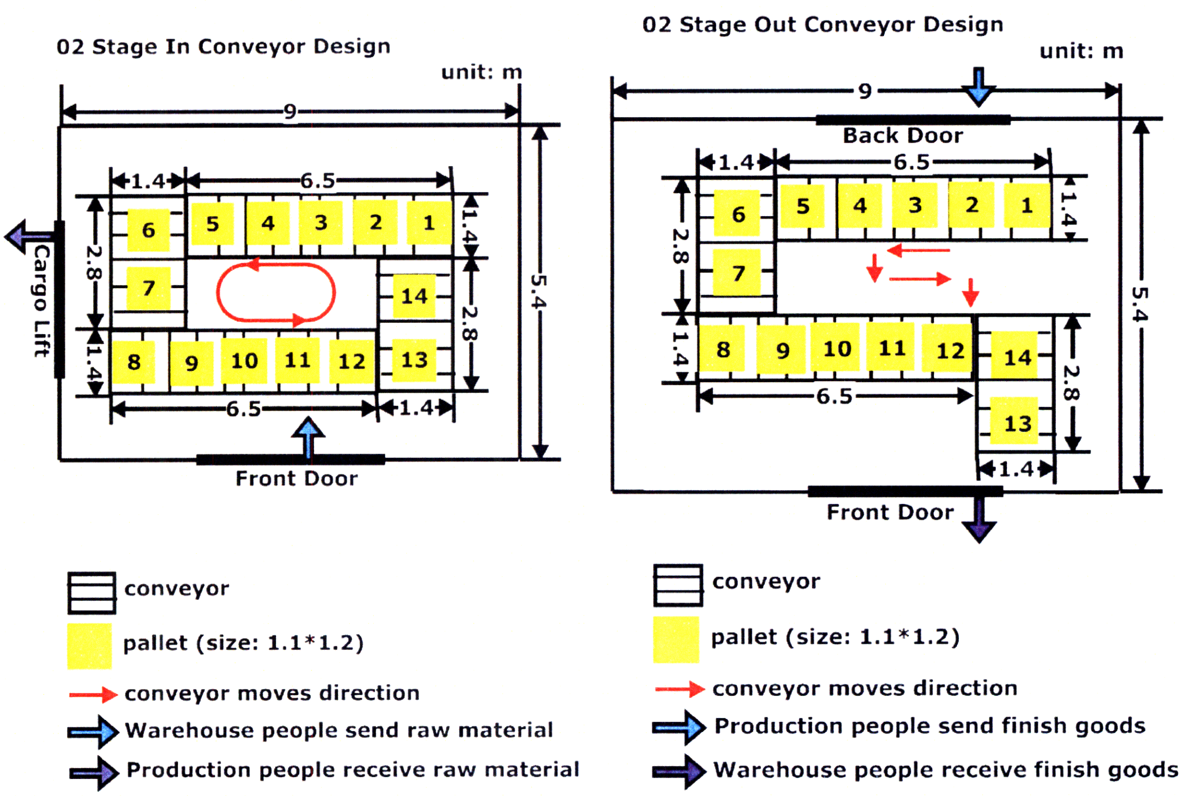

Figure 20 Conveyors in Stage In and Stage Out

There is still time taken for the movement within the staging areas after installing the conveyors. According to the vendor specification, it takes about 1 minute on average for the pallet to travel from the conveyor to the unloading point. Currently we spend about 4 minutes on space adjustment. Thus we have a 75% time reduction in space adjustment in the staging areas. The capacity utilization is re-forecasted based after installing the conveyors. As shown in Table 21, the utilization is largely decreased after installing the conveyors. The year of exceeding the utilization cap is postponed by two years for the best case.

Table 21 Capacity utilization forecast after installing conveyors

Duration(best)	2007	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	1.00
Material	2.98	4.85	6.43	9.57	12.42	15.99	19.31	22.86	26.27	28.84
Waste	1.00	1.63	2.16	3.21	4.17	5.37	6.48	7.67	8.82	9.68
Total	4.98	7.48	9.59	13.79	17.59	22.36	26.78	31.53	36.09	39.52
Utilization	12.8%	19.2%	24.6%	35.4%	45.1%	57.3%	68.7%	80.8%	92.5%	101.3%
Duration(worst)										
Human	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Material	3.59	5.84	7.74	11.53	14.95	19.25	23.24	27.52	31.63	34.73
Waste	1.50	2.44	3.24	4.82	6.25	8.05	9.72	11.51	13.23	14.52
Total	6.59	9.79	12.48	17.85	22.71	28.80	34.46	40.53	46.36	50.75
Utilization	16.9%	25.1%	32.0%	45.8%	58.2%	73.8%	88.4%	103.9%	118.9%	130.1%

6.3 Additional Shift

Our current material handling operation can be extended to achieve the same performance as the conveyor solution. i.e. we can extend the daily working hours by 4 hours or extend the daily shift by half a shift. As shown in Table 22, the forecasted capacity utilization is about the same for the additional shift solution as the conveyor solution.

Table 22 Capacity utilization after having additional shift

Duration(best)	2007	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	1.00
Material	4.08	6.64	8.80	13.10	17.00	21.88	26.42	31.28	35.95	39.47
Waste	1.00	1.63	2.16	3.21	4.17	5.37	6.48	7.67	8.82	9.68
Total	6.08	9.27	11.96	17.31	22.17	28.25	33.90	39.95	45.77	50.15
Utilization	12.5%	19.0%	24.5%	35.5%	45.5%	57.9%	69.5%	81.9%	93.9%	102.9%
Duration(worst)										
Human	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Material	4.68	7.63	10.11	15.05	19.53	25.14	30.35	35.94	41.31	45.35
Waste	1.50	2.44	3.24	4.82	6.25	8.05	9.72	11.51	13.23	14.52
Total	7.68	11.57	14.85	21.37	27.28	34.69	41.57	48.95	56.04	61.37
Utilization	15.8%	23.7%	30.5%	43.8%	56.0%	71.2%	85.3%	100.4%	115.0%	125.9%

6.4 Financial Analysis

A financial analysis was performed to determine the most cost-effective solution between the conveyor and the additional shift solutions. As shown in Table 23, each conveyor costs $44,000 and 4 conveyors will be implemented. This is compared with the additional 4 hours/day extension for the current material handling operation which operates with 3 labors per shift

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Table 23 Cost parameters for the conveyor and the additional shift solutions

Cost parameter	Value
Unit conveyor cost	$44,000
Number of conveyors installed	4
Annual maintenance cost per conveyor	$2,000
Hourly labor cost	$15
Additional hours/day	4
Number of labors/shift	3
Annual discount rate	11%

Table 24 Annual expenses for the conveyor and additional shift solutions

	NPV	2011	2012	2013	2014	2015	2016
Conveyors	$193,567.18	$164,000	$8,000	$8,000	$8,000	$8,000	$8,000
Add. Shift	$236,075.42	$0	$63,875	$63,875	$63,875	$63,875	$63,875

As suggested by Table 24, the Net Present Value (NPV) is calculated as the compounded total cost over the next 6 years at the annual discount rate. The annual expense of additional shift solution is further illustrated below.

$$Annual\ Expense = Addtional\ hours\ /\ day \times labors\ /\ shift \times days\ /\ year \times labor\ \cos t\ /\ hour$$

$$Annual\ Expense = 4\ hours\ /\ day \times 3\ labors\ /\ shift \times 358\ days\ /\ year \times \$15\ /\ hour = \$63{,}875$$

The NPV suggests that the conveyor solution is a more cost-effective than the additional shift solution. $42,508 can be saved in the next 6 years by implementing the conveyors.

7 Recommendation and Conclusion

Based on the performed analysis, there will be a capacity problem with the current material handling operations in year 2012. Besides the capacity problem, the existing number of pallet spaces in the staging areas could also be a bottleneck in future. According to the queuing model analysis in Section 5.5, the pallet spaces in staging will not be a constraint until year 2016. Therefore we shall be able to prevent the capacity problem from occurring by implementing solutions in year 2011.

The space adjustment and the transportation are the most time-consuming segments of the material movement. The proposed Kanban layouts for Product A and Product B1 can save space adjustment time. The conveyors automate the staging areas and can postpone the capacity problem by at least a year. The conveyor solution is also shown to be most cost-effective solution, compared to adding additional shift to the forklift truck drivers. Conveyors also serve as the loading and unloading tools for any material handling automation. The implementation of conveyors in 2011 builds the platform for further automation in material handling in the future.

8 Bibliography

[1] Changhui Zhao., Strategic and Operational Plan for Better Material Handling, Thesis Study of Master of Engineering in Manufacturing, Massachusetts Institute of Technology. 2008

[2] Michael ten Hompel. and Thorsten Schmid., Warehouse Management: Automation and Organization of Warehouse and Order Picking Systems, Springer, Inc. 2007

[3] Dematic Singapore, PowerPoint Presentation, May 2008

[4] Stephen C. Graves, Inventory Basics, 15.762 Supply Chain Planning Class PowerPoint Presentation, Massachusetts Institute of Technology, February 2008

[5] Stephen C. Graves, Review of Queuing Model, 15.763 Manufacturing Systems and Supply Chain Design Class PowerPoint Presentation, Massachusetts Institute of Technology, April 2008