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AUTONOMY IN MOBILE FULFILLMENT SYSTEM: GOODS-TO-MAN PICKING SYSTEM

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ABSTRACT

Nowadays, issues regarding to e-commerce unpredictability become a problem in warehouse operations. This unpredictability is make difficult by fulfillment challenges. Designing a goods-to-man picking system and dispatching order strategy based on service in random order (SIRO) can be one of promising alternative to reduce AGV empty travel distance. The focus is on the warehouse operations, start from item classification on dynamic slots location, multi-attribute AGV dispatching rules and AGV battery management. The system aims to minimize total cost of AGV by assign the multi-attribute dispatching rules and bidding process to get on time delivery as many orders that can be completed, dealing with minimum battery-charging effects on the system operation. The planning system considers dynamic nature of customer order demand, and the simulation based development is used to model real time dynamic slots storage location and AGVs availability. The computational experiments showed this methodology most likely could reduce total cost by perform more than one AGV in operating systems

Keywords : *automated warehouse, goods-to-man picking system, dynamic slots storage location, battery management, simulation model*

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CHAPTER 1
INTRODUCTION

This introduction part explains about research background and objective, research position, scope and constraints, and also research framework.

1.1 Research Background

The rapid growth of e-commerce in the past decade, and the opportunity for automation of order fulfillment hit new heights. This is, increasingly causing capacity constraints to key supply chain components such as warehousing space, capacity and flexibility, labor availability and IT system processing capacity. Fully automated e-commerce warehouse suited to operations which have sufficiently high volume. In general, the larger the warehouse and the smaller the order size, the more travel is required, unless an order picking solution can be adopted through mechanization and system integration.

In e-commerce fulfillment, automation is not necessarily about replacing people but about making those people more efficient and productive. The increasing collaboration between human workers and robots provides another way to improve productivity and work experience. The major advantage of automation of order fulfillment is their ability to scale up quickly by adding more robots, moving racks or work stations and relatively cheaply in comparison to traditional warehouse.

In Kiva System, where humans and robots work side-by-side, capable of fulfilling orders up to 70% faster than a non-automated warehouse (Accenture, 2015). While robots perform picking and delivery, human workers spend more time on overall process improvements such as directing lower-volume products to be stored in a more remote area. One of the things that makes the Kiva system so attractive from an algorithmic point of view is that, while the overall computational problem is an intractable, dynamic, stochastic optimization with incomplete information, it is amenable to decomposition into very approachable sub-problems. It remains to be seen whether approaches that address the global optimization problem perform better than those that decompose the problem. In the following, this paper (Enright & Wurman, 2011) highlight some of the sub-problems :

1. Inventory pod selection problems
2. Pod storage allocations
3. Order allocation problems
4. Replenishment allocation problems
5. Robot allocations problems

A dispatching normally resorts to the first-come-first-served (FCFS) strategy, which is applied to prioritize waiting transportation orders (Grunow, Gunther, & Lehmann, 2006). The pitfall of FCFS is that, it is not able to reduce vehicle empty travel distance and not be able to prioritize a task with fastest due date, because of that, we assign order it based on service in random order (SIRO). (Rogiest, Laevens, Walraevens, & Bruneel, 2015) stated that random order of service provides a well-known alternative with significant progress in the homogeneous customer service demands.

In this study, we try to minimize travel distance by assign moving racks based on througput-to-storage ratio and assign AGV under dispatching rules. Because moving racks also need to deliver to picking stations by AGV, there is a complex coordination that must take place to smoothly remove one pod and bring in its replacement with as small a time gap as possible.

1.2 Research Objective

The main objective is to minimize total cost by assign the multi-attribute dispatching rules and bidding process to get on time delivery as many orders that can be completed, dealing with minimum battery-charging effects on the system operation. Because in our system, we given a large set of moving racks that need to be delivered and set of AGV that are free or soon to be free, we have a straightforward matching problem associate the AGV to moving racks, with the objective of minimizing travel distance.

According to the problem, the question that need to be answered by this research is *"Do the total cost of AGV can progressively reduced by assign AGV under dispatching rule in dynamic slots location to minimize battery charging effects on the system?"*

1.3 Research Scope

The problem considered herein is single-item-small-quantity orders in existing pick-by-order warehouse. In the process, we dealing with dynamic nature of customer orders.

Basically there are two main problems that we address here, first is utilizing AGV by assign the multi-attribute dispatching rules based on shortest travel time or largest travel time depend on the AGVs current location, AGVs battery level and order's priority. For order with high priority, we examine a certain value of each available AGV in bidding process and conclude which AGV can works better to delivers the order than the others.

The second is assignment for dynamic slots location, to decide which moving racks should be assigned to which slots location. The planning system considers dynamic nature of customer order demand and configuration of moving racks location. We use simulation based to solve this stochastic problem, because the system need to update the number of empty slots location and AGVs availability whenever orders are coming.

In this study, we try to minimize travel distance by assign moving racks based on througput-to-storage ratio and assign AGV under multi-attribute dispatching rules and bidding process using simulation model. Simulation based development is used to modelling real time dynamic slots location and AGVs availability.

1.4 Research Constraints

There are certain limitations regarding the proposed approaches. In this research, the problem was constrained in these few things:

1. Warehouse systems are opened for 8 hours
2. Racks and AGV are shared and schedule resources.
3. No need to consider dynamic model of AGV (acceleration, gravity and motion) and tuning procedure of AGV
4. The layout of guide paths and storage slots point has been determined
5. The slots storage and slots charging are assumed to be limited for a certain number of space

1.5 Research Framework

Research framework explains step by step to do this research, starting point from identifying the problem, formulate the research objective, review some literature related to the topic and also find state of the art of framework autonomy in mobile fulfillment system area, defining real system then create sets of simulation procedure for modeling the problem.

In the end by this study, the final step is make conclusion whether the proposed model can create the better result and suggestions for the future research. Detail of the framework of this research as shown in Figure 1.1

1.6 Organization of Thesis

The first chapter describes research background, objective, scope and constraints and research frameworks. Chapter 2 explains all literature review related to the problems, such as order initiated dispatching and dynamic slots allocation. Chapter 3 describes how to develop simulation under multi-attribute dispatching rules and dynamic slots location rule. Chapter explains parameter settings of simulation, simulation results with different scenarios, and discussion about the results. The last chapter describes conclusion and future works.

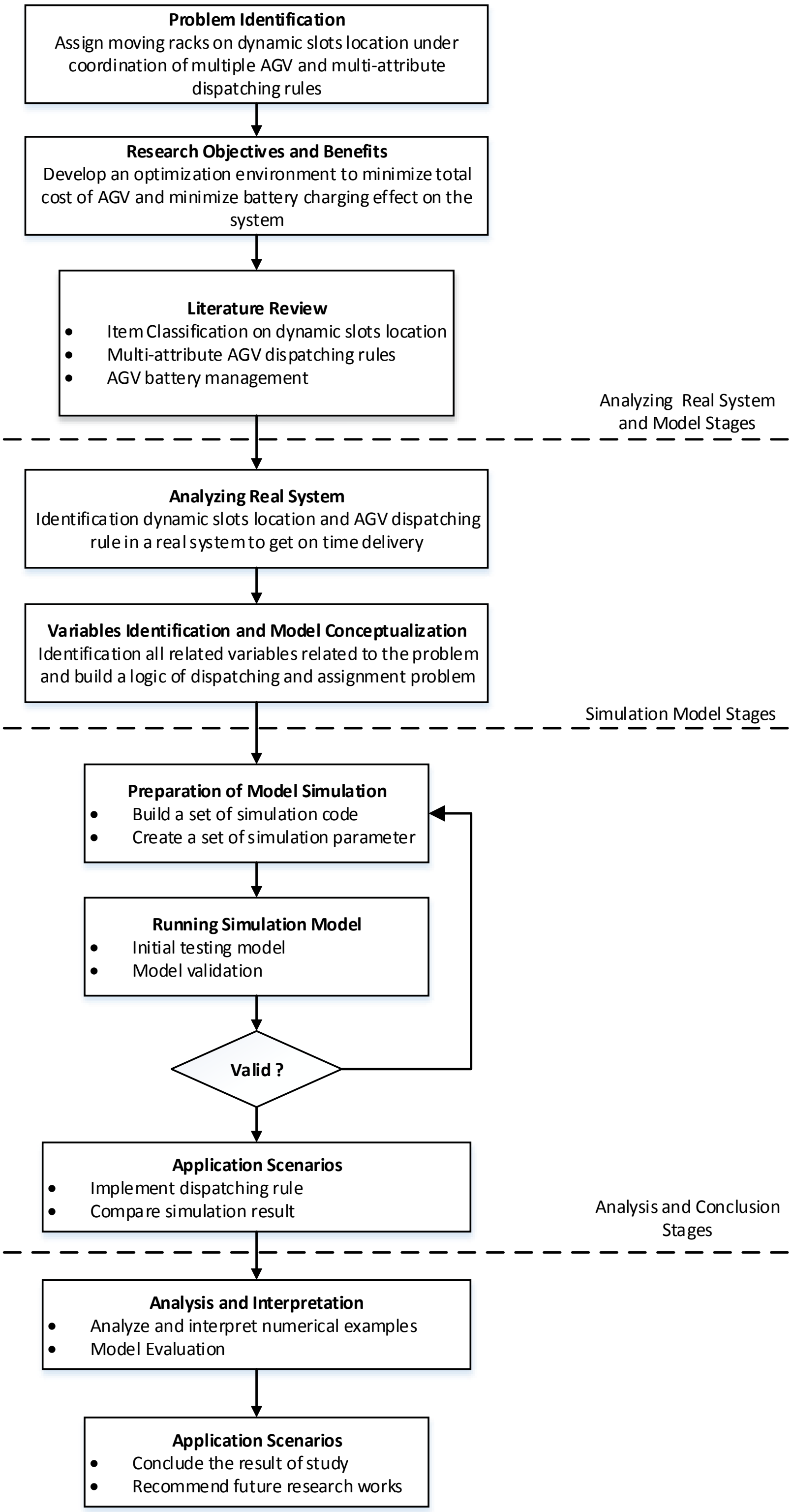

Figure 1.2 Research Framework

CHAPTER 2
LITERATURE REVIEW

This chapter describes some literatures related to this study. It includes important literatures related with warehouse design and warehouse operation. In warehouse design section, extensively review past related research in layout design. In warehouse operation section, explored related research in item classification on dynamic slots location, multi-attribute AGV dispatching rules, AGV battery management, and guide path design for multiple AGV.

2.1 Warehouse Design

Warehouse design is a main issue in warehouse management. (Hsieh & Tsai, 2006) state that based from the labor requirement point of view, currently, most of the distribution center still belongs to labor-intensive industry, and the labor cost directly related to the order picking operation occupies even above 50% of the overall cost.

2.1.1 Layout Design

In the context of order picking, the layout design relate to with two sub-problem: the layout of the facility containing the order-picking system and the layout within the order picking system (de Koster, Le-Duc, & Roodbergen, 2007).

Decision problems in design and control of order-picking processes problems deals with: layout design (the layout of the facility containing the order picking system and internal layout design or aisle configuration problem) and storage assignment or location, zoning, batching, routing methods, policies (de Koster et al., 2007).

(Thomas & Meller, 2015) explain more about developing design guidelines for a case-picking warehouse should be include of size and layout of the forward area (to increase picking efficiency by placing fast moving items in a smaller area), pallet area and dock door configuration using pallet sizing algorithm and analytical model to quantify the space and labor requirement.

2.2 Warehouse Operations

2.2.1 Item Classification on Dynamic Slots Location

In picking distance minimization, the most intuitive way to assign a storage location is based on item turnover. Picking distance can be reduced by assigning the highest turnover item to the location closest to the picking station and vice versa. In addition, assigning policy that considers the relationship between products has recently emerged, referred to as the family grouping method in (de Koster et al., 2007).

(Lin & Lu, 1999) proposed a two steps order picking heuristic. The first step is to classify orders into five categories based on order quantity (EQ) and number of order items (EN). (Liu, 2004) state that if a certain combination of items appears frequently in one common order or picking list, then the probability to simultaneously select these items in one picking trip can be relatively high. The design of stock location based on throughput-to-storage ration can reflect the differences in activity levels and storages requirements among products to be stored. Let *Ti* denoted the throughput per unit time for item *i, Si* denote the storage requirement for item *i*, and item t_i denote the throughput-to-storage ratio for item *i*. Then throughput-to-storage ratio can be defined as follows.

$$ti = \frac{Ti}{Si} \tag{2.1}$$

For *i*, *k=1,..,K*

According to the formula above, a larger t_i value implies a greater popularity for item *i*. Those items with larger throughput-to-storage ratios should be allocated to the storage locations near the picking stations.

(Chuang, Lee, & Lai, 2012) examine the viability of clustering-assignment problem model by assign storage locations by frequency-based popularity which is ranked by item frequency (IK). (Kim & Smith, 2012) present a mathematical formulation for solving the slotting problem. One of the heuristics presented solves the slotting problem using simulated annealing improvement heuristic based on correlated carton list.

2.2.2 Multi Attribute AGV Dispatching Rules

A key element in the control of automated guided vehicle systems (AGVs) is dispatching policy. Dispatching involves deciding about the assignment of a particular AGV to particular transportation order.

According to (Bilge et al., 2006) AGV dispatching heuristics that appear can be grouped with regard to their decision making approaches as follows: (i) single attribute dispatching rules based on only one parameter such as the AGV empty travel time; (ii) hierarchical dispatching rules based on combining two or more criteria sequentially in a hierarchical method; (iii) multi attribute dispatching rules that allow key parameters of their aggregate decision function to be tuned through feedback obtained from the system have self-adaptive capability.

Ideally, AGV should appear at places where the most urgent order are, so that, the items don't wait for AGV, thus the rate can be improved. There are many strategies in vehicle dispatching. With the infrastructure and the data availability, the feasibility and effect of those strategies will also be different.

(Hwi Kim & Hwang, 1999) proposed a multi attribute dispatching rule based on the bidding concept, and tested dispatching algorithm to prevent blocking and starvation and reduce travel time, which results in improvement of the system throughput. (Wu, Mok, & Zhang, 2011) proposed an adaptive multi parameter based on dispatching policy, it is demonstrated that the proposed approach has better performance in terms of cycle time, throughput, due-date satisfaction rate, and vehicle utilization compared to conventional single- and multi-attribute dispatching.

In these case, multi attribute in autonomy in mobile fulfillment system, various parameters such as AGV location, travel time and battery level have been considered in the vehicle dispatching models.

2.2.3 AGV Battery Management

Battery management is important for vehicle management. The function of battery management is to ensure that batteries level have sufficient energy to perform the current order of the AGV. Obviously AGV need to be charged after certain operating period.

However, in a reality there is a possible effect on performance as an AGV with status nearly out of batteries are unavailable to deliver order under a certain distance limitations. (McHaney, 1995) present three types of charging schemes: (i) opportunity charging – uses natural idle time in AGVs cycle to replenish batteries, (ii) automatic charging – an AGV runs until its battery is depleted to a certain level and then the scheduler assign this AGV for charging, (iii) combination system – this is a combination of the previous two

(Ebben, 2001) give an explanation about AGV has to change its battery, one of the battery slots has to be selected. Several heuristics rules are possible:

1. Nearest battery station
2. Farthest reachable battery station on the current route
3. First battery station encountered on the current route
4. Battery station that leads to minimum delay

In addition, we also have to consider the capacity of the battery charging slots stations (are they sufficient locations for AGV), and the AGVs next order, so we can add some other rules, such as go to the next order closest to AGV charging station. On the other hand, we can minimize battery charging effects on the system to make sure the AGV do not stop all of a sudden and block other AGV on the way they deliver the order.

2.2.5 Guide Path Design for Multiple AGV

Guide path design is an important problem in AGV system design. (T. Le-Anh & M. B. M. D. Koster, 2004) describe that the guide path depends greatly on the allocation of space, layout of storage zones and the arrangement of handling stations. The AGV guide path usually represented such that aisle intersections, pick-up and delivery (P/D) locations can be considered as nodes on a graph.

(Vis, 2006) describe the layout of the flow path can be designed in various ways. Firstly, the layout of the building, the layout of the flow path and the location of pickup and delivery points can be simultaneously determined. Secondly, the design of the flow path and the location of pickup and delivery points can be determined by considering the layout of the facility as an input factor. Thirdly, the flow path can be designed, considering the layout of the facility and the location of pickup and delivery points as input factors.

Many modern AGV systems do not use fixed guide-paths. The guide paths may, for example, be computer programmed and uploaded to the AGV' controllers. The flexibility of changing guide paths demands a capability to adapt the guide path system fulfill new systems requirements.

Table 1 briefly explains the previous researches done in several topics related to the main point in autonomy in mobile fulfillment system area.

Table 2.1 State of The Art

No	Author	Adding	Methodologies
1	(Thomas & Meller, 2015)	developing design guidelines for a case-picking warehouse should be include of size and layout of the forward area to increase picking efficiency	placing fast moving items in a smaller area
2	(Le-Anh & R. M. B. M. d. Koster, 2004)	introducing new and efficient multi attribute dispatching rules for AGV system with many vehicles	simulation to perform modified multi-attribute dispatching rule
3	(Bilge et al., 2006)	presents additive multi attribute dispatching rule by employ two attributes: output buffer length and travel time	parametric and dynamic approach
4	(Vidović & Ratković, 2015)	presents possible solving approaches considering the optimal assignment of resources (batteries and vehicles) to material handling task	mathematical models for scheduling pairs battery-vehicle on tasks

Based on the literature review there is no research which focused on integrating between dynamic slots storage location and multi attribute AGV dispatching rule by incorporate decisions about batteries, in order to get minimum total cost of AGV. Therefore this research can contribute to fulfill that gap.

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CHAPTER 3
METHODOLOGY

This chapter explains about the methodology which combine simulation and optimization approach. Simulation is used to model dynamic slots storage location in a real time and optimization approach is used to decide the best assignment policy.

3.1 General System Environment

The environment part of framework comprises modeling construct that capture in an explicit manner a number of key characteristics and relations that are pertinent for modeling dynamic environment.

A graphical sketch of the environment layout plan considered in this paper is given in Figure 3.1. The warehouse is rectangular and consist of a number of parallel storage aisles and number of slots storage. We assume the distance path designed using Manhattan. Note that the slots storage location can potentially influence the travel time of AGV. The distance information shows in Appendix.

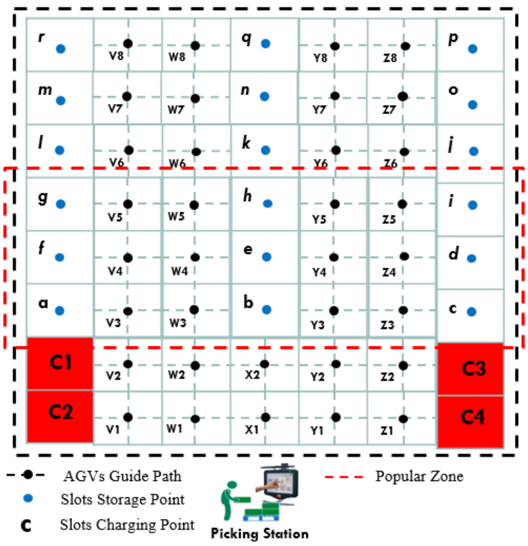

Figure 3.1 Environment Layout Plan

The structure of the simulated warehouse environment is modeled in terms of environmental entities and environmental layout that arranges the entities with respect to each other. To represent a physical environment, we construct environment layout presented as follows in Table 3.1:

Table 3.1 Environmental Layout

Storage Location	**Charging Station**	**Picking Station**	**AGV Guide Path**
System only have 18 slots storage point	System only have 4 slots charging point	System only have 1 picking station	allow no more than one AGV
Storage point divided into 2 zones : popular and unpopular		Picking station only have 10 slot incoming order list	give conflict-free and shortest-time routing solutions for AGVs

To represent dynamism explicity in the simulation model, we put forward an activity as a modeling construct. The association between activity and environmental entity are presented as follows in Table 3:

Table 3.2 Environmental Entities

Order	**Items**	**Moving Racks**	**AGV**
Orders are defined by a list of *line items*	Each item consists of single item	System only have nine moving racks	System only can activate several AGV
Each order only have single item	No-need replenishment item process	Each moving racks only hold one types of item	AGV can carry only one moving racks at a time

Table 3.3 Environmental Entities (continue)

Order	Items	Moving Racks	AGV
		Initial location for moving racks begin from random arrangement	AGV themselves are shared. No-swap job between AGV
		Moving racks location changes are possible	

3.2 General System Framework

This research implements real time operation about dispatching AGV using multi attribute rule and bidding process to get on time delivery as many orders that can be completed especially for high priority order. A dispatching normally resorts to the first-come-first-served (FCFS) strategy, however the pitfall of FCFS is that, it is not able to reduce vehicle empty travel distance and not be able to prioritize a task with fastest due date, because of that, we assign order it based on random order of service.

Different ways from VRP problem, in VRP, vehicle will not run into collision because they are regarded as moving point when they run on the path network. In AGV routing, the basic consideration is to give free-collision and shortest time routing solution for AGV.

For battery management, it is important to ensure that batteries level of AGV have sufficient energy to perform the current order. In practice, charging station often coincide with the AGV storage locations to save space and use the positions for opportunity charging. For example if an AGVs battery getting lower until certain level, those AGV only allowed to deliver items from popular zone. In other word, the AGV battery charging scheme should also be considered explicitly when AGV are schedule for operations.

In our system, we given a large set of moving racks that need to be delivered to picking station and park to storage location considers dynamic nature of customer order demand. When considering the dynamic nature of customer demand orders, the system center needs to periodically review the number of order arrival and modify the slots storage location accordingly. Figure 3.2. represent general system framework of automated warehouse in dynamic storage location that we developed in this research.

The design of slots storage location based on throughput-to-storage ratio. According to the throughput-to-storage ratio, a larger value implies a greater popularity. Those items with larger throughput-to-storage ratios should be allocated to the popular zone. A scheme of rack arrangement is given in Figure 3.3.

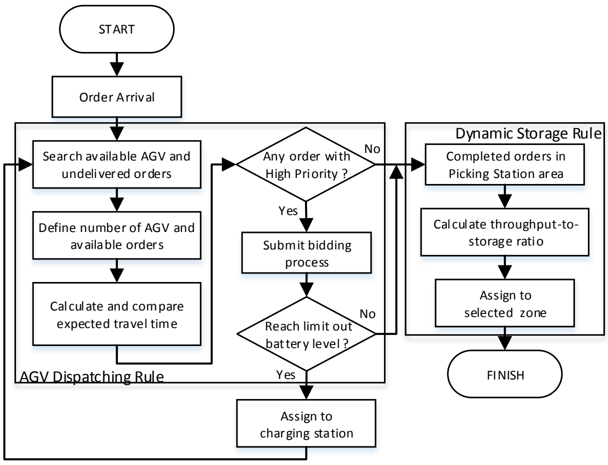

Figure 3.2 General System Framework

Different from the traditional warehouse which are open only 8 hours per day schedule, this automated warehouse system opened for 24 hours, because our consumers expect their online purchases to be delivered faster than ever.

The AGV can travel 60 minutes operating hours with 5 minutes charging time. The AGV travel at a speed of about 3 miles/hour or 1.34 meters/second which is similar to walking speed. Since the AGV full of battery, the AGV attempt to delivery as many orders that can be completed. The orders time arrival, due date, priority and type are approach using random generations which explains further on the next part.

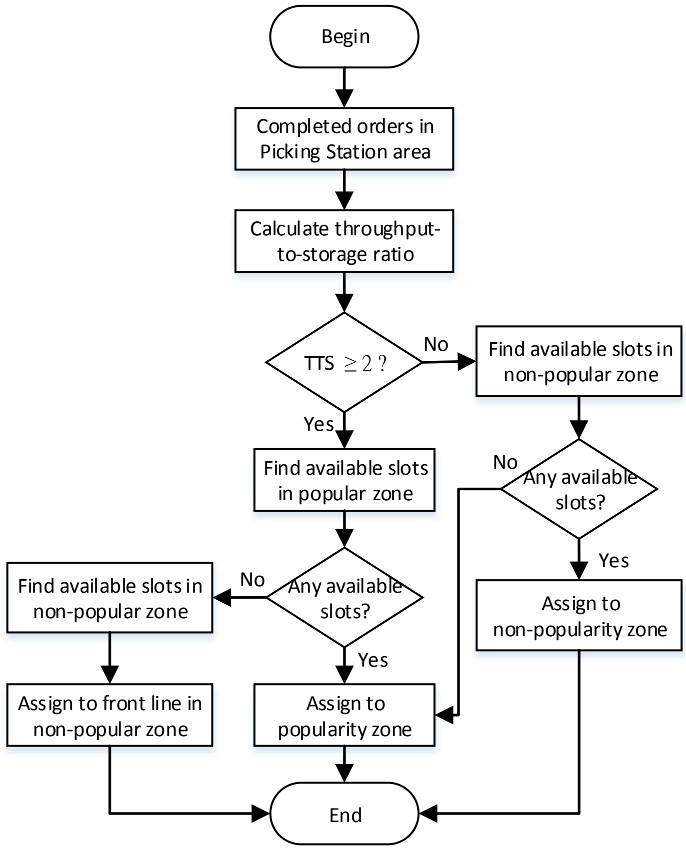

Figure 3.3 Rack Arrangement Scheme

3.3 Travel Timeline

Travel time of each AGV may vary over the time. It would depend on the previous slots location assign by the system. In this model, for a single time AGV move the racks from its current location to deliver items to picking station, queueing in front of picking station, stopping by for picking operation (pick, scan, and put in a box) and move it back to slots storage location, system will recognize it as a *travel tim***e**. The time that should be captured in this activity is *Q* as queue time and *T* as a total travel time.

In this case, before we assign AGV to go to particular rack, system needs to consider the *expected travel time*, start from (i) calculate transferring time of AGV to the next rack, (ii) calculate transferring time from slots storage location to deliver items to picking station and, (iii) calculate transferring time to move the racks back to its destination zone, all get minimum distance for remaining AGV.

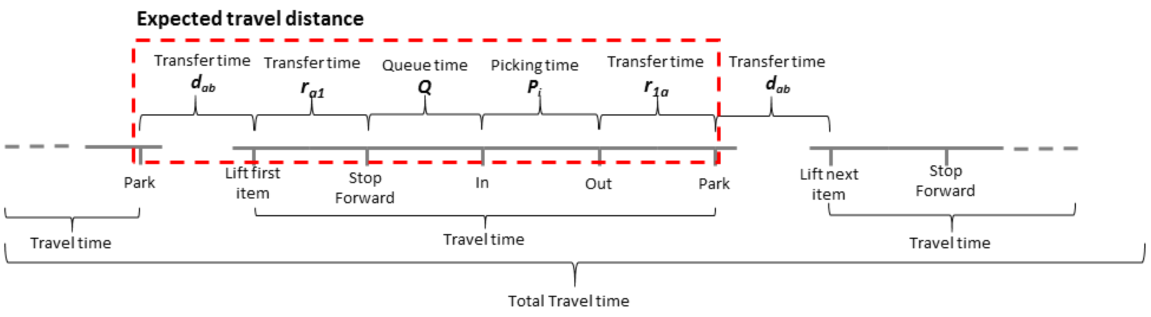

Figure 3.4 Travel Timeline

3.4 Objective Function

The objective function of this model is to minimize total cost by counting the transportation orders completed on time with travel distance as short as possible by incorporate AGVs batteries. This function consider penalty cost for orders which cannot be completed until they pass the due date period. Then we can write the problem as:

Minimize:

$$TC = \sum_{i=1}^{N}(Ti + Pi) \quad (3.1)$$

where :

$Ti = travel\ time\ to\ serve\ order\ i\ \times\ travel\ cost/time$

$Pi = penalty\ order\ i$

$$Pi = \begin{cases} 0, \ if\ travel\ time < due\ date\ i \\ (due\ date\ i - travel\ time\ i) \times \frac{cost}{time}, \quad other \end{cases}$$

3.4 Multi Attribute AGV Dispatching Rules

3.4.1 AGV Dispatching Rules (Number of AGV ≤ Number of Orders)

In this case, a new AGV becomes available after completed a task and AGV has to choose an item from a set of order request, in a condition the number of available AGV is smaller than or equal to the number of available order. A scheme of AGV dispatching rule is given in Figure 3.5.

The dispatching procedure consider three attributes; battery level, order's priority and expected travel distance. In this case, to avoid uncompleted order with largest expected travel distance, because the system has minimum number of AGV than the number of orders. AGV with full battery level will assign to deliver order with largest expected travel distance from its current location.

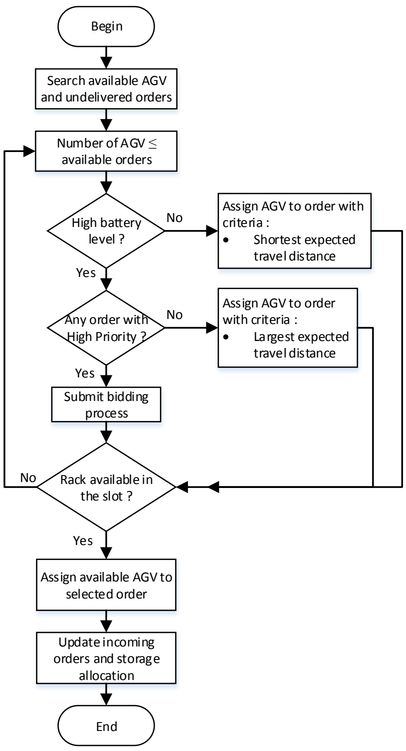

Figure 3.5 AGV Dispatching Framework (AGV ≤ Orders)

3.4.2 AGV Dispatching Rules (Number of AGV > Number of Orders)

In this case, a new AGV becomes available after completed a task and AGV has to choose an item from a set of order request, in a condition the number of available AGV is larger than the number of available order. A scheme of AGV dispatching rule is given in Figure 3.6.

The dispatching procedure consider three attributes; battery level, order's priority and expected travel distance. In this case, because the number of available AGV is larger than the number of available order, the possibility AGV to moving around to complete even for largest expected travel distance is bigger. AGV with full battery level will assign to deliver order with shortest expected travel distance from its current location.

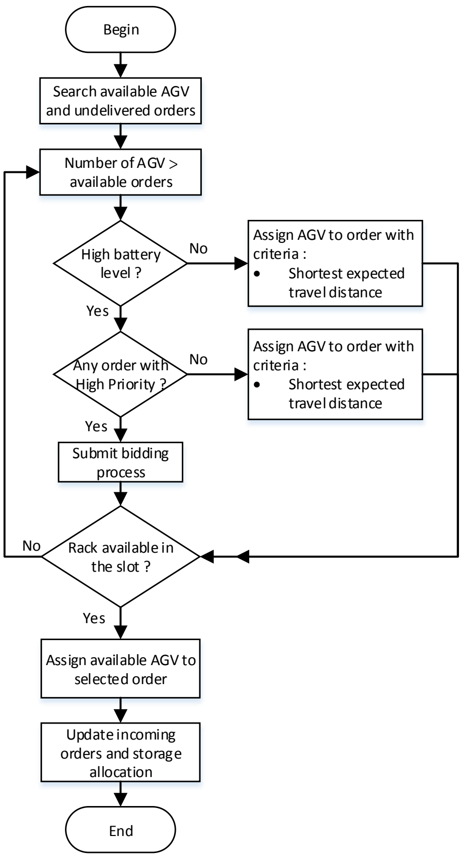

Figure 3.6 AGV Dispatching Framework (AGV > Orders)

3.5 AGV Bidding Rules

This paper suggest a dispatching method based on a bidding rule. The bidding rule assumes a system in which AGV attempt to consume battery as much as possible by performing delivery order with high priority at the shortest travel time by assign AGV at the lowest possible for the remaining battery level. The basic environment consists of:

- Bidders *i* = 1, …., n AGV
- Bidders *i* observes an information (signal)
- Bidders *i*'s information is independent of other bidders information

Given the basic set-up specifying a set of rules will give rise to a game between bidders:

1. Define number of available AGV and available incoming orders, if in an order list there are order with high priority then do bidding process
2. Bidder AGV *i*'s will wins if the expected travel distance shorter than other AGV
3. Bidder AGV *i*'s will wins if the battery level sufficient to transfer the order
4. If there are two AGV with the same possible value (based on point 2 and 3), choose the AGV with lower remaining battery level

3.6 AGV Battery Management

When an AGV's battery runs out, it must drive to a charging station. To evaluate the charging strategy of AGV, the AGV should simulate the energy consumption. Determining the energy consumption could be an important issues, because in that way it is determined the vehicles availability, as well the time when the battery must be charged at a charging station and the interruption of an AGV's operation in case it runs out of energy. The battery consumption are comprises three cases components:

High battery level characteristics:

1. 60 – 31 minutes battery energy remaining, assumed as high level battery
2. AGV can deliver any kind of order; high priority or low priority based on bidding process decision with shortest or largest expected travel distance, depend on the AGV dispatching rule

Low battery level characteristics:

1. ≤ 30 minutes battery energy remaining assumed, as low level battery
2. AGV can deliver any kind of order; high priority or low priority based on bidding process decision with shortest expected travel distance

Limit battery level for charging process:

1. If AGV only has 2 minutes battery energy remaining, the system should drive it to a charging station.
2. The AGV will takes 5 minutes to fully charged

3.7 Simulation Approach

Simulation is used to model real time dynamic order arrivals and AGV availability which always need to update by the time. Further discussion is about how we conduct the simulation, starts from the initialization until collecting the result.

In this study, we develop an algorithm of integrating between dynamic slots storage location and multi attribute AGV dispatching rule by incorporate decisions about batteries. Because we don’t have the real data, so we generate demand by random order. Setting parameters are used to determine the conditions which may generate optimal solution, by this simulation approach. Some parameters that we can set as input of simulation are :

a. Arrival time is generated in Uniform distribution by time in advance
b. Number of AGV
c. Types of item
d. Due date of orders

CHAPTER 4
NUMERICAL EXPERIMENT

4.1 Parameter Determination

Based on parameter settings, the operating warehouse system will be opened for 8 hours. The order are generated using a Poisson distribution. The Poisson distribution is defined by one parameter: lambda (λ). This parameter equals the mean and variance. As lambda increases, the Poisson distribution approaches a normal distribution. The distribution generated intensity $\lambda = 2$, $\lambda = 4$, $\lambda = 6$, $\lambda = 8$, and $\lambda = 10$. We also assumed the penalty cost 50 NT/hours for order which cannot completed during the due date. We assume the warehouse only have one picking station with service picking time 5 seconds/item. Simulation was done using MATLAB 2015a in Intel 173.8 GHz Processor with 8 GB DDRAM, Windows 7-64 Bit. Table 4.1 shows some parameters are used to conduct the simulation:

Table 4.1 Parameter Used

Operating hours system	8 hours
Penalty cost	50 NT/hours
Service picking time	5 seconds/item

.

4.2 Simulation Result

Based on the simulation approach we can determine the total cost to expect the value of any future orders that may arrive later which done by SIRO to optimally manage dispatching AGV and to reach completion time. Experiment was done due to compare the total cost and average queueing time in picking station. Table 4.2 shows the comparison of total cost for some cases.

Table 4.2 Comparison of Total Fitness Cost

No		**Total Fitness Cost / runs**

	Lambda order	1 AGV	2 AGV	3 AGV	4 AGV	5 AGV
1	2	$3.517.207	$1.858.403	$1.329.182	$1.034.439	$911.096
2	4	$874.913	$434.160	$305.641	$245.251	$200.087
3	6	$381.343	$182.497	$127.823	$99.200	$80.764
4	8	$209.700	$103.787	$66.517	$50.253	$43.947
5	10	$130.725	$62.500	$40.308	$30.549	$24.311

Result shows that the total cost always give the decreases in value within the changes on order demand intensity, and the total cost also give decreases in value between the changes of number of AGV. This condition means, the numbers of AGV increase will affect in reducing total cost.

The total cost consist of total cost and penalty cost, we try to describe the relation between those two kinds of cost. Table 4.3 shows the comparison of total cost for some cases.

Table 4.3 Total Travel Cost Comparison

No	**Lambda order**	**Total Cost / runs**				
		1 AGV	2 AGV	3 AGV	4 AGV	5 AGV
1	2	$499.19	$100,393.32	$144,180.43	$165,594.09	$185,294.71
2	4	$251.19	$24,454.68	$33,564.65	$42,107.92	$43,290.21
3	6	$167.68	$11,772.73	$15,059.04	$17,620.62	$19,059.51
4	8	$125.49	$6,988.62	$9,075.40	$10,004.17	$11,481.38
5	10	$100.74	$4,130.23	$5,438.42	$6,655.96	$6,850.05

Result shows that the bigger number of AGV we operate in our warehouse, the total cost will be higher as well, so it will effects to the opportunity for order to be deliver on time will be higher. By comparing with the total penalty cost, the unexpected cases will be analyze further. Table 4.4 shows the comparison of penalty cost.

Table 4.4 Total Penalty Cost Comparison

No	Lambda order	Total Penalty Cost / runs				
		1 AGV	2 AGV	3 AGV	4 AGV	5 AGV
1	2	$3,516,708	$1,758,010	$1,185,002	$868,845	$725,801
2	4	$874,662.07	$409,705	$272,076	$203,143	$156,797
3	6	$381,174.84	$170,724	$112,764	$81,579	$61,705

Table 4.5 Total Penalty Cost Comparison (continue)

No	Lambda order	Total Penalty Cost / runs				
		1 AGV	2 AGV	3 AGV	4 AGV	5 AGV
4	8	$209,574.41	$96,799	$57,442	$40,249	$32,466
5	10	$130,624.51	$58,369	$34,869	$23,893	$17,461

In this case, we can found that cost comparison between total cost and total penalty cost has a large gap (as illustrated in figure 4.1, figure 4.2, figure 4.3, figure 4.4, and figure 4.5).

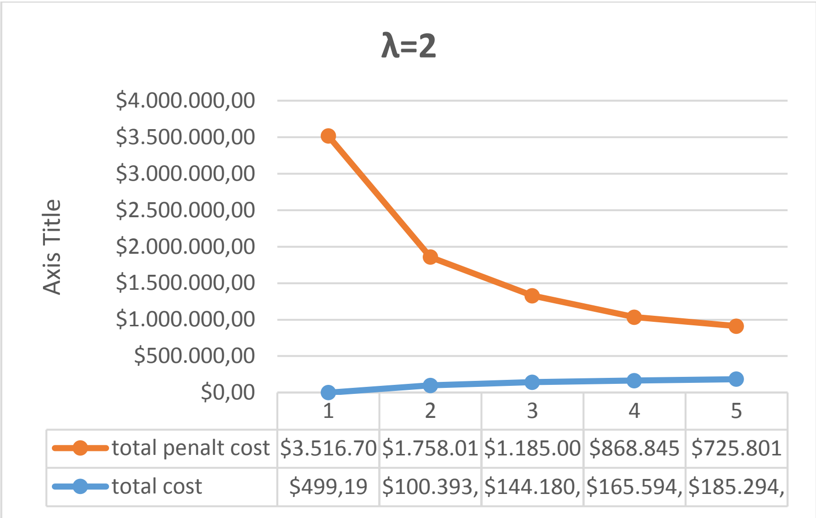

Figure 4.7 Comparing cost (lambda=2)

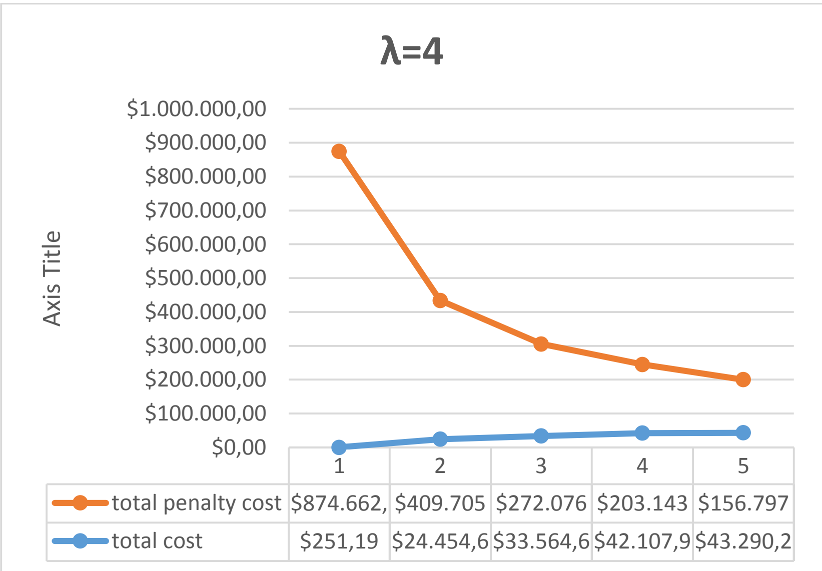

Figure 4.8 Comparing cost (lambda=4)

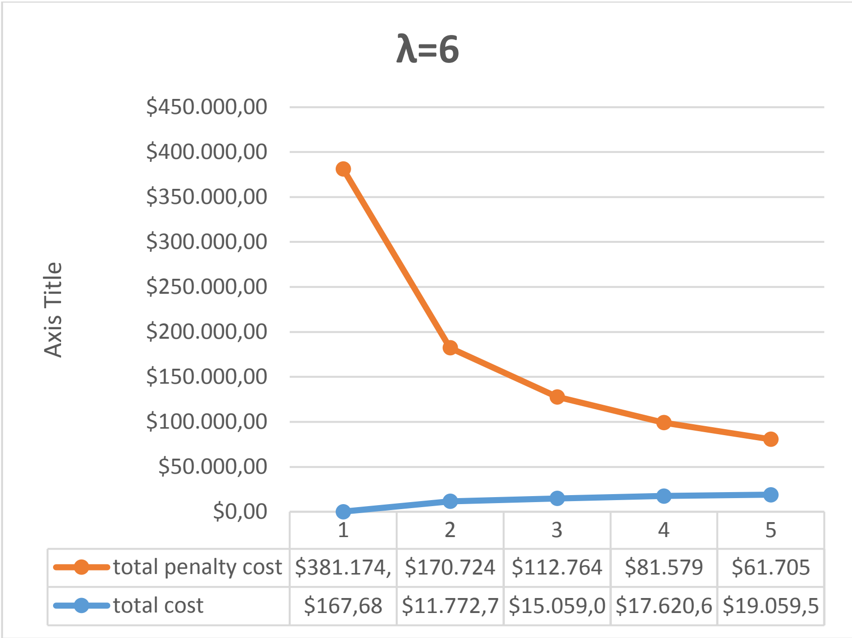

Figure 4.9 Comparing cost (lambda=6)

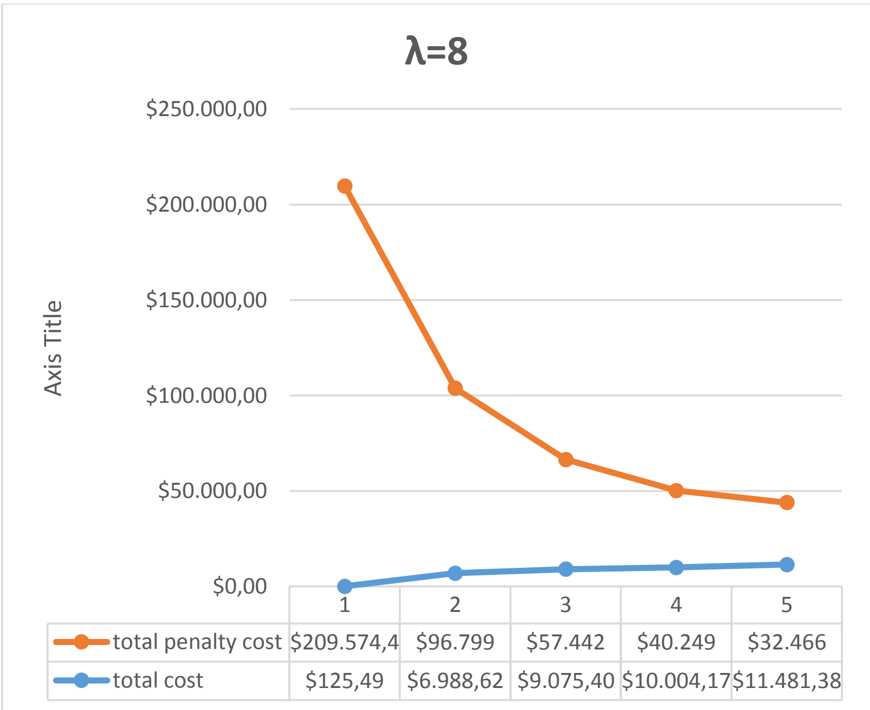

Figure 4.10 Comparing cost (lambda=8)

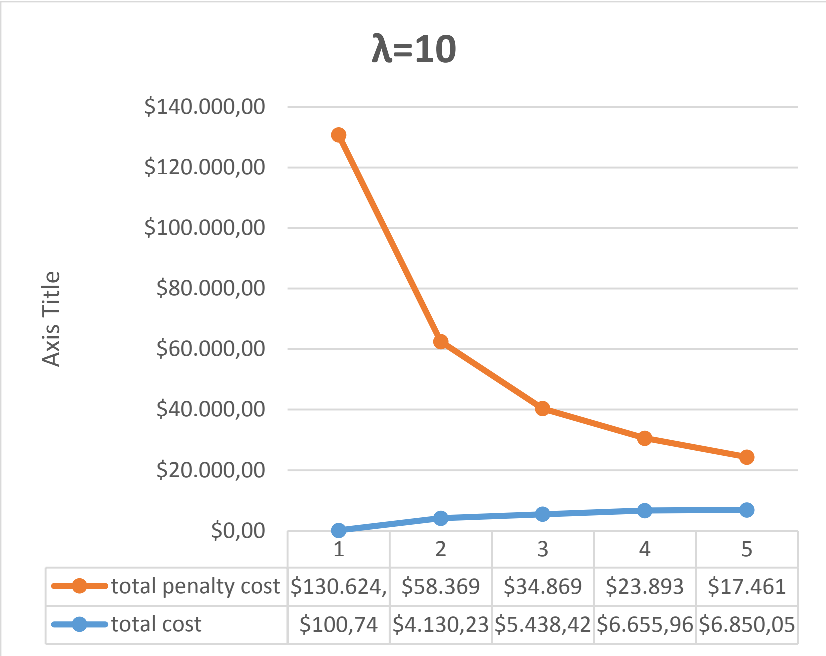

Figure 4.11 Comparing cost (lambda=10)

It can be shown from the figure, the bigger number of AGV perform, will effect to increasing in total cost and decreasing in total penalty cost, still those cost cannot exceed one another, which means we have a many order haven't finish during the due date, so that the penalty cost will still be high.

When we dealing with coordinating multiple AGV inside our warehouse, the queue time should be our attention. The queue time start when the AGV already move the racks forward but in the way they deliver, will be stopped by the other AGV which on the service picking operations.

Table 4.5 shows the comparison of average queue time for some cases in different number of AGV and order demand intensity.

Table 4.6 Comparison of Average Queue Time (hours)

No	Lambda order	Average Queue Time/runs				
		1 AGV	2 AGV	3 AGV	4 AGV	5 AGV
1	2	0	6.89	9.83	11.50	12.7
2	4	0	3.38	4.61	5.80	6.05
3	6	0	2.45	3.08	3.64	3.97
4	8	0	1.90	2.50	2.79	3.10
5	10	0	1.40	1.86	2.26	2.35

Result shows that the average queue time for each case between the changes of number of AGV and order demand intensity always give the increase value if we performs with more than one AGV. We can conclude that by coordinating multiple AGV in operation system can affect the queue time in picking system. And the bigger number of AGV will follow with the increasing of queue time.

From AGV point of view, the average number of order served by each AGV can be shown in table 4.6.

Table 4.7 Average Number Order Served

lambda	AGV order served				
	1	2	3	4	5
2	14372				
2	7195	7189			
2	4811	4811	4797		
2	3626	3613	3607	3571	
2	2902	2895	2917	2857	2827

Result shows that the order served by AGV always divided equally, so the AGV is fully utilize to serve any order, the percentage shown in table 4.7.

Table 4.8 Percentages AGV Performance

lambda	percentage AGV performance (%)				
	1	2	3	4	5
2	100				
2	50	50			
2	33	33	33		
2	25	25	25	25	
2	20	20	20	20	20

4.4 Discussion

This study shows that the proposed method, most likely can reduce total cost if we perform with number of AGV more than one vehicles and the important reason now is how to prioritize the order to minimize total penalty cost. The challenging of this part of this problem is integrate all of aspect, and predict which aspect will have significant effect to the system and its objective

If we compare to other study with others, actually this study more complicated, because we are not only consider one aspect in term of assignment but also need to have a good understanding in build warehouse layout. The advantage of doing simulation is we can model the real problem without using a real warehouse.

CHAPTER 5

CONCLUSIONS

5.1 Conclusions

This study proposed an algorithm to represent the AGV dispatching process in dynamic slots storage location. By implement this rule, system can manage the environment situation when the number of AGV and the number of available order has different value. This study shows that the proposed method, most likely can reduce the total cost if we perform more than one AGV in operating system.

However, for the instance with larger number of AGV and moving racks for future works still need to be improved.

5.2 Contribution

The development model conducted in this research had differences with other studies. The work in this thesis makes the following contributions:

1. In practical
    - Battery management consideration can help to minimize battery-charging effects on the system operation
    - Rack arrangement by considers dynamic nature of customer order demand can help to minimize travel distance between storage area and picking station
2. In academic

- Develop algorithm of AGV dispatching rule in dynamic slots storage location

5.3 Future Research

Future research may focus on developing automation of order fulfillment system by using the following further assumptions:

- Consider multiple item inside the racks
- Consider heterogeneous item types
- Consider replenishment process in warehouse operation system
- Involve AGV with sensors and navigation system

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