A Quasi-Three-Dimensional Allocation Algorithm for Space Scheduling Problems

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碩士論文

擬似三維配置演算法
在空間排程問題的應用

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ABSTRACT

A space scheduling problem is an important issue of work efficiency for high-tech equipment manufacturers. The existing approaches to solve a space scheduling problem always cause orders (jobs) to be completed too late or too early. It brings huge financial penalties to manufacturers.

In this study, the purpose of this research is to find a schedule to r total penalties (early and tardy penalties) for a space scheduling problem. A new space allocation algorithm, namely, Quasi-Three-Dimensional Space Allocation Algorithm (QTDSA) was developed. We compared its performance for different performance indicators with those of the Northwest Algorithm (NWA) and Longest Contact Edge Algorithm (LCEA) by different dispatching rules.

In addition, randomized block designs and factorial designs were employed for statistical analysis. The results demonstrated that the QTDSA is more effective than the other space allocation algorithms in reducing total penalties. It also has better performances for some other performance indicators (i.e. number of early jobs and total earliness) than the other algorithms. The performance of the QTDSA and the other algorithms are about the same for the other performance indicators (makespan, number of tardy jobs, total tardiness and space utilization). In the final part of the research, suggested dispatching rules and suggested space allocation algorithms for each performance indicator were also provided.

Keywords: Scheduling problems, Quasi-Three-dimensional, Space allocation, Space scheduling problem, Dispatching rules, Early and tardy penalty

擬似三維配置演算法在空間排程問題的應用

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摘要

空間排程問題對於高科技設備製造商的工作效率來說是一個重要的議題，現存解決空間排程問題的方法總是會造成訂單延遲或過早被完成，這為製造商帶來巨大的財務上的懲罰。

本研究針對此問題發展出一新的空間配置演算法，命名為「擬似三維空間配置演算法」，並與西北演算法和最大接觸法，運用不同的派工法則，比較各項績效指標的表現。本研究目的為對空間排程問題，找到一個排程計畫來減少總懲罰(提早與延遲懲罰)。

根據隨機集區實驗與因子實驗結果分析，本研究證明擬似三維概念空間配置法相較於以前的空間配置演算法可更有效降低提早與延遲訂單的懲罰成本。它在其它一些績效指標也比其他演算法有更好的表現 (提早訂單數、提早總天數)，且它在其餘績效指標的表現也不輸給其他演算法(製距、延遲工作數、總延遲天數、空間利用率)。雖然此演算法並沒有在所有的績效指標都有突出的表現，但它對於整個問題有更完整的思考性。在研究最後，針對不同績效指標建議採用的派工法則和空間配置演算法也在實驗中被獲得。

關鍵字詞：排程問題、擬似三維、空間配置、空間排程問題、派工法則、提早懲罰和延遲懲罰

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Chapter 1 Introduction

1.1 Background

In recent years, the high-tech industries of Taiwan have had an outstanding performance in the international environment. In order to reduce production costs, the high-tech industries, such as TFT-LCD (Thin Film Transistor-Liquid Crystal Display) and semiconductor manufacturers began to purchase automation equipments and parts of non-critical manufacturing equipments from local manufacturers. For these equipment manufacturers, the building expenses of a factory are much higher than traditional machinery manufacturers. In addition, a huge space is needed for machinery assembly. Therefore, the space of the shop floor becomes a very important resource. Because the machines for high-tech equipments are huge and not easy to move, utilizing the space of the shop floor efficiently becomes a significant issue.

In Taiwan, most high-tech equipment manufacturers schedule orders (jobs) in a manual way. The production personnel decide a sequence for handling jobs and appropriate working spaces by themselves. But scheduling and space allocation of a large number of orders is too complicated. The production personnel have no idea how to do these efficiently. They need a useful rule and tool which can help them solve the complex scheduling problem quickly and efficiently. Perng *et al*. (2007, 2008a, 2008b, 2008c, 2009) defined it as a space scheduling problem and indicated that the job sequence and space allocation of jobs will determine the performance of a schedule.

1.2 Motivation for the research

In the space scheduling problem, the machine assembly process requires a certain amount of complete space on the shop floor in the factory for a period of time. The sizes of the shop floor and machines will determine the number of machines which can be assembled simultaneously. If the factory has not enough space to contain a new arrival job, the new job must wait for a space which is currently occupied by existing jobs to become available. As shown in Figure 1.1, job D2 can't be assigned into the factory due to limited space and has to wait until other jobs on the shop floor are completed. Figure 1.2 shows that job B1 is done and left and there is enough space to contain job D2. In this research, we assume that the shape of spaces required by all orders is rectangular.

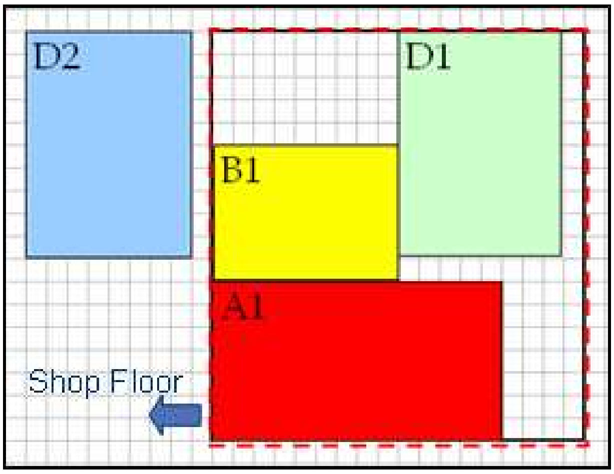

Figure 1.1 An example of space constraints

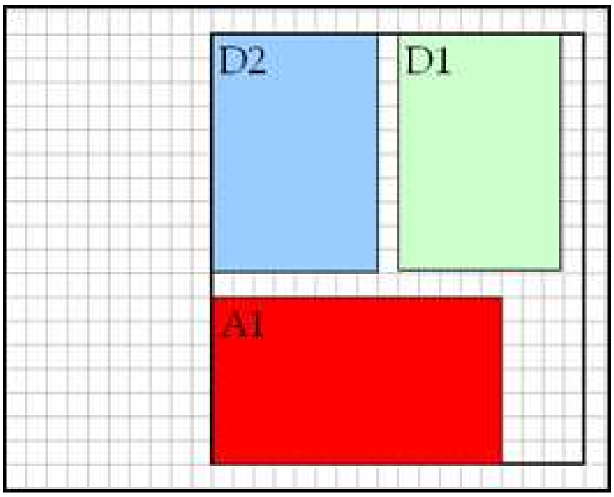

Figure 1.2 Allocation of a new order

According to previous literature (Perng *et al*., 2007, 2008a, 2008b, 2008c, 2009), we found that the existing allocation approaches for the space scheduling problem always cause jobs to be completed too late or too early. If orders are completed too early, the manufacturer has to find extra space to store those finish products until the due date. If orders are completed too late, the manufacturer will not only have to pay financial penalties but also damage its reputation.

1.3 Objectives of the research

Both tardy and early jobs bring financial penalties to manufacturers. In order to reduce early and tardy penalties (i.e. total penalties), an approach to solve this problem must be developed.

The objectives of this research are to minimize the total earliness and total tardiness in a space scheduling problem. A new space allocation algorithm, namely, Quasi-Three-Dimensional Space Allocation Algorithm (QTDSA) will be developed. We will compare performance measurements, namely, makespan, total tardiness, total earliness, space utilization, the number of tardy jobs, and the number of early jobs, among the Northwest Algorithm's (NWA), Longest Contact Edge Algorithm's (LCEA), and our proposed QTDSA. In addition, suggestions will be made under different scenarios for management.

1.4 Organization of this Thesis

The remainder of this dissertation is organized into six chapters. In Chapter 2, previous work related to this research is reviewed. Chapter 3 introduces research methodology. It includes descriptions of Quasi-Three-Dimensional Space Allocation Algorithm. Chapter 4 describes the design of experiments. Chapter 5 presents results and discussions. These include the results obtained from QTDSA and comparisons among different allocation algorithms. Finally, conclusions for this research are presented in Chapter 6.

Chapter 2 Literature Review

Space scheduling problems are scheduling problems with limited space capacity. In this chapter, we will first review literatures for scheduling problems. Next, space allocation approaches in the previous researches will be examined. In the final section of this chapter, literatures related to the objectives of this study (i.e. early and tardy penalties) and previous researches for space scheduling problems will also be reviewed.

2.1 Scheduling Problems

Pinedo (2002) defined that the goal of production scheduling is to maximize the efficiency of the operation and reduce costs. Chretienne *et al.* (1995) defined a scheduling problem as a triplet $\alpha \mid \beta \mid \gamma$. The α field describes the resource environment. The β field shows characteristics and constraints of production processes. The γ field is the objective of the scheduling problem. Haynes *et al.* (1973) proposed three heuristic rules in production sequencing and examined their effectiveness. In their research, they scheduled n jobs in a single production facility. The objective was to minimize the downtime due to setup changes. This research indicated that job sequence could affect the scheduling performance.

Axelrod (1976) found that each job has its submission time in a computer system. If a job can not acquire the resource it requires, it will be held until a completion of a previous job. It can be defined as a resource-constrained scheduling problem. Machines and process flows were not considered in this problem. In their research, sequencing rules were also developed for solving this problem. Hardin *et al.* (2008) proposed a time-indexed formulation for a resource-constrained scheduling problem. In the problem, each job's resource requirements were constant over its processing time. The effectiveness of this formulation was also proved in their research.

The other factors for scheduling problems are dispatching rules. Dispatching rules play an important role in determining the sequence of jobs. Holthaus and Rajendran (1997) stated that dispatching rules normally help determine which job should be processed when the machine becomes free. They also categorized dispatching rules into four classifications as follows. (1) The rules based on process time, such as SPT (shortest process-time rule) and LPT (longest process-time rule) belong to this category. (2) The rules based on due date, such as EDD (earliest due date) belongs to this category. (3) The combinative rules, for example, least slack rule belongs to this category. (4) The rules which are neither process-time based nor due-date based, for instance, WINQ rule (total work-content of jobs in the queue of next operation of a job) belongs to this category. Pugazhendhi (2004) stated that the performance of a dispatching rule would be influenced by various parameters. He also proposed that no single rule has been found to be the best for all conditions. Mizrak and Bayhan (2006) investigated the performance of dispatching rules in a real-life job shop environment. They compared dispatching rules and provided suggested rules which were effective for this type of systems. The rules includes FCFS (first come first serve), SPT (shortest processing time), WSPT (weighted SPT), WLWKR (weighted least work remaining), EDD (earliest due date), MDD (modified due date), SLACK (least slack), CR (critical ratio), S/OPN (slack per remaining operation), MDSPRO (modified slack per remaining operation), S/RPT (slack per remaining processing time), ODD (operation due date), OSLACK (operation slack), OCR (operation critical ratio), ATC (apparent tardiness cost), COVERT (cost over time), SB (shifting bottleneck) and WINQ (work in next queue). They also provided guidance to determine effective dispatching rules for this job shop scheduling problem in their research. In this study, four typical dispatching rules (SPT, LPT, FCFS, and EDD) were employed with space allocation algorithms for space scheduling problems.

2.2 Space allocation problems

In this study, the space allocation approach is also an important factor which will affect the utilization of the shop floor in a factory. Space allocation problems are extensively related to many science problems, such as printed circuit board design, layout design of buildings, computer memory control, and warehouse problems. Space allocation problems can be looked back on a knapsack problem. This problem supposes that a hiker has to fill up the knapsack by selecting among various possible objects which have different weights and values, and he or she should maximize total value of the knapsack without unacceptable total weight (Martello and Toth, 1990). Dantzig (1957) gave an efficient approach to determine the solution to the continuous relaxation of the problem, and he started a serious study on the knapsack problem. Gilmore and Gomory (1965) investigated the dynamic programming approach for the knapsack problem and other similar problems. Johnson (1973) proposed heuristic algorithms for finding approximate solutions to various polynomial complete optimization problems including the knapsack problem.

In space scheduling problems, the jobs on the shop floor change at different time. It is similar to the dynamic layout problems (DLP). Erel *et al.* (2003) defined the dynamic layout problem as the situation where the alterations of the traffic among the various units within a facility occurred over time. Its objective was to determine a layout for each period and minimize the total material flow and the relocation costs. They proposed a new heuristic scheme to solve this problem. Balakrishnan *et al.* (2003) found that an optimal solution method based on dynamic programming can not solve the large dynamic plant layout problems (DPLPs) practically. So they created a hybrid genetic algorithm based on the use of genetic algorithms and proved this proposed algorithm was effective for the problems. Dunker *et al.* (2005) combined dynamic programming with genetic search and proposed a new algorithm for solving a dynamic facility layout problem. A model which can deal with the problem of unequal sizes that may change form in different periods was described in their research. Mckendall and Shang (2006) developed hybrid ant systems (HASs) for the dynamic facility layout problem (DFLP). They used two data sets which were from the literature to test the performance of the meta-heuristics. The efficiency of the HASs for solving the DFLP was proved in their research.

In a space scheduling problem, orders which are appropriate to be assembled at the same time are assigned on the shop floor as many as possible.

It is similar to a bin packing problem or a container loading problem (CLP). A bin packing problem determined how to put the most objects in the least number of fixed space bins. More formally, a partition and assignment of a set of objects was found such that a constraint was satisfied or an objective function was minimized (or maximized) (Johnson, 1974). Sleator (1980) developed a bin packing problem into a 2D bin packing problem and proposed a 2.5 times optimal algorithm to solve it. Ikonen *et al.* (1997) investigated a unique 3D bin-packing problem with non-convex parts having holes and cavities and employed a genetic algorithm (GA) as the solution approach for it. Lewis *et al.* (2005) developed a distributed chromosome genetic algorithm to improve the genetic algorithm for rapid prototyping (GARP). Their objective was to reduce the execution time of GARP for the 3D bin packing problem. They used multiple CPUs to help solve the problem and investigate the efficiency of this distributed GA. Bischoff (2006) focused on the development of a new heuristic approach for a 3D bin packing problem where the cargo had varying degrees of load bearing strength. The results demonstrated that the approach was better than other approaches which had been proposed for this problem. Sciomachen and Tanfani (2007) investigated the approach to optimize stowage plans for containers in a ship. It is a master bay plan problem (MBPP). They made use of the relation with the 3D bin packing problem to develop a heuristic method for this problem. Their objectives were to minimize the total loading time and maximize the efficiency of the quay equipment. Puchinger and Raidl (2007) proposed new integer linear programming formulations which included models of a restricted version and an original version for the three-stage two-dimensional bin packing problem (2BP). The experiments of their research documented the benefits of the new approaches. The model of the restricted version could obtain near-optimal solutions quickly, and the model of the unrestricted version was more expensive to obtain the computation. Gehring and Bortfeldt (1997) proposed a genetic algorithm to solve the CLP. They produced a set of box towers from a strongly heterogeneous set of boxes and arranged the box towers into a single container according to a given optimization criterion. They demonstrated that the GA was efficient for the CLP by comparing the GA and several other procedures. Eley (2002) used a greedy heuristic and improved it by a tree search for solving the heterogeneous single and multiple container loading problems. In the research, he also considered load stability and weight distribution within the container. Bortfeldt *et al.* (2003) developed a parallel tabu search algorithm based on the concept of multi-search threads for a CLP with a single container. In their research, they focused on the case of a weakly heterogeneous load. The performance of the algorithm was demonstrated by comparing it with other loading procedures from the literatures. Lee and Hsu (2007) stated that pre-arrangement of the containers could improve the operational efficiency which was affected by the need to re-shuffle containers so they developed a mathematical model to minimize the number of container movements for the container pre-marshalling problem. Several possible variations of the model are also discussed in their research. Cumulative resource constrained job scheduling problem (CRCJSP) was applied to a container loading problem (Kovacs and Beck, 2008). In their integer programming mathematical model, the boxes must to be located inside the container, and an overlap must not occur between boxes. They proved that the model was efficient for reducing the search space, and it could find better solutions or the same solutions faster.

Some layout researches are also highly related to this study. Tsai *et al.* (1993) developed a standard mixed 0-1 integer programming model for the three-dimensional pallet loading problem. Barbosa-Povoa *et al.* (2001) proposed a mathematical model to optimize the two-dimensional layout of industrial facilities by minimizing the connectivity cost. A Mixed-Integer Linear Problem (MILP) was developed in their research. In the MILP, binary variables which characterized topological choices and continuous variables which described the distances and locations were presented. Barbosa-Povoa *et al.* (2002) converted and extend a Mixed Integer Linear Programming (MILP) formulation which they had proposed for a two-dimensional layout problem to solve a 3D multi-floor continuous space layout problem. A set of representative examples was used to demonstrate the applicability of their model.

However, this research found that a space scheduling problem has two characteristics which make it differ from other space allocation problems. One of the characteristics is that each order has it own space requirement and appropriate time when order can be assembled without any penalties in a space scheduling problem. The other characteristic is that the purpose of the space scheduling problem is to determine a scheduling scheme to optimize performance measurements instead of only choosing objects to optimize the space utilization.

2.3 Early and Tardy Penalties

The earliness and tardiness (ET) problem was called the minimum weighted absolute deviation problem previously until it has been referred to as the ET problem in about 1990 (Ahmed, 1990). Liaw (1999) applied a branch-and-bound algorithm to minimize the sum of weighted earliness and weighted tardiness without considering machine idle time for the problem of scheduling a given set of independent jobs on a single machine. Wan and Yen (2002) believed that either a tardy job or an early job brought extra costs in just-in-time (JIT) manufacturing. The objective function of a schedule should include both job earliness and tardiness as penalties. In their research, a tabu search (TS) procedure was used with the optimal timing algorithm to find final schedules for minimizing total weighted earliness and tardiness in a single machine scheduling problem. Lauff and Werner (2004) extend the objective function to multi-stage environments from a single-stage scheduling problem by two main approaches they proposed. In their research, if the jobs were completed early, the intermediate storage costs were brought. Their research was a starting point to develop appropriate algorithms for multi-stage scheduling problems with earliness and tardiness penalties. Thiagarajan and Rajendran (2005) found that the jobs which were completed early must be held as finished-goods inventory until their due dates in many manufacturing systems so earliness costs were incurred. Similarly, the tardy completions of jobs brought penalty. They minimized the sum of earliness and tardiness of jobs by the dispatching rules because earliness and tardiness of the jobs influenced the performance of a schedule with respect to cost greatly in dynamic assembly job-shops. Pathumnakul and Egbelu (2006) stated that a job in the shop had a tree product structure consisting of components and sub-assemblies which may need additional processing until the end product was assembled. In their research, a heuristic was developed to minimizing the weighted earliness penalty in assembly job shops. Schaller and Gupta (2008) developed a heuristic algorithm based on the concept which grouped jobs into families to let orders as close as possible to their due dates on a single machine with family setup times. Their objective was minimizing total earliness and tardiness of jobs. Su (2009) stated that the total earliness and tardiness about a common due date are minimized according to the minimum total flow time in an identical parallel machine system. He proposed a streamlined binary integer programming model and proved that the model outperformed the existing optimization algorithm for the problem.

The purpose of the earliness and tardiness problem is to force jobs to be completed as close to their due dates as possible because both early and tardy penalties bring commercial cost. The idle time is also a factor which needs to be avoided for machines with high operating costs because the cost of keeping the machine running is higher than the earliness cost made by completing a job early. In this study, high-tech equipment manufacturers focus their work on assembling large machines on a shop floor. Idle time was not an effective factor on the whole problem so the loss of idle time was not considered.

2.4 Space Scheduling Problems

Perng *et al.* (2007, 2008a, 2008b, 2008c, 2009) defined a job scheduling problem with space resource constraints as a space scheduling problem. It is a newly risen research, and it includes several different studies such as resource constraint, scheduling and space allocation problems. A space scheduling problem is different from other scheduling or space allocation problems, appropriate approaches need to be developed for satisfying different objectives.

There are few literatures about solving space scheduling problems.

However, these researches have rudimentary achievements. Perng *et al.* (2007) proposed two new dispatching rules, namely, small space requirement first (SSR) and large space requirement first (LSR), to solve a space scheduling problem. They also developed the Northwest Algorithm to allocate jobs on the shop floor. A space scheduling problem with space obstacles was proposed (Perng *et al.*, 2008a) later. The obstacles represent pillars and the space which can not be used on the shop floor. Perng *et al.* (2008b) applied container loading problem (CLP) heuristics into a space scheduling problem. Perng *et al.* (2008c) proposed a new algorithm based on NWA, namely, Longest Contact Edge Algorithm (LCEA). It was more efficient than NWA for obtaining better performances. Perng *et al.* (2009) developed an algorithm, Northwest corner searching algorithm to schedule jobs into the shop floor. The objective of the research was to minimize early and tardy costs in space scheduling problems.

According to literature, this study found that the existing approaches to solve a space scheduling problem always cause jobs to be completed too late or too early so tardy and early jobs bring financial penalties to manufacturers. In order to reduce early and tardy penalties, a new approach was developed for reducing early and tardy costs in the next chapter.

Chapter 3 Research Methodology

3.1 Problem assumptions and notations

In a space scheduling problem, each order (job) has its arrival time, processing time, and due date, and they need a certain amount of space to be assembled on the shop floor. In order to simplify this problem, this research proposed several assumptions as follows:

1. The shape of all orders' space requirements is a rectangle.
2. After assigning an order, the order's location on the shop floor won't be moved until completion of processing.
3. This research doesn't consider heights of spaces which the orders require.
4. An order can't share its working space with others. In other words, a working area can't be occupied by more than one order at the same time.

For this problem, a space which an order requires was represented by a box Let a_k denote the width of job k. Let b_k denote the length of job k. a_k and b_k represent the length and width of a box. Let p_k denote the processing time of job k. In this research, p_k represents the depth of a box. Figure 3.1 shows an example of boxes representing working space requirements of orders.

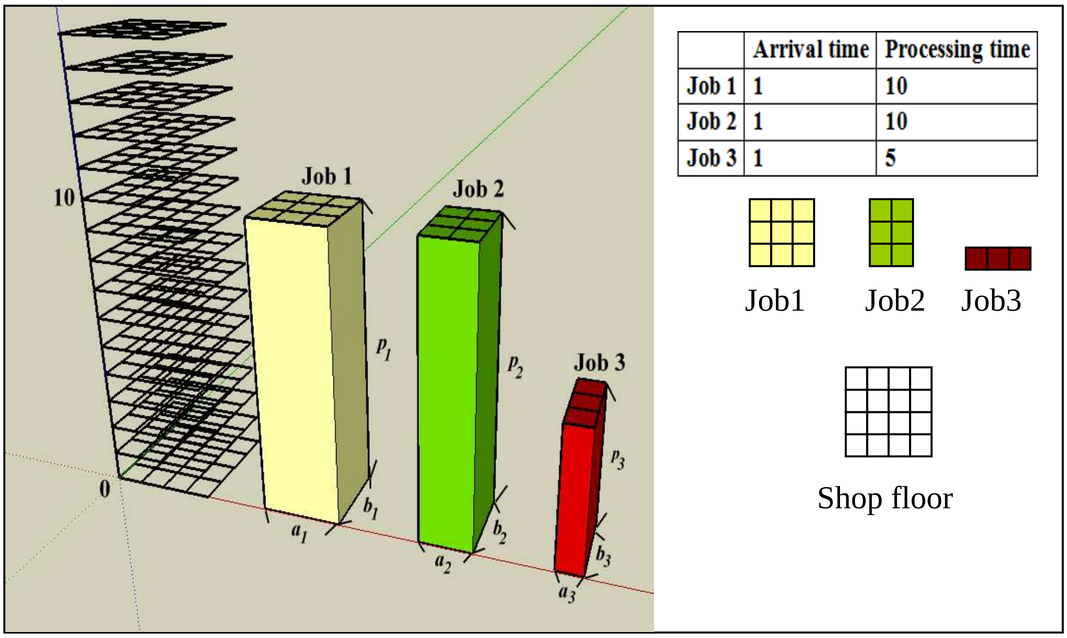

Figure 3.1 An example of boxes representing space requirements of orders

In this research, *n* orders need to be assigned into the shop floor. We let N denote a set of *n* jobs and r_k denote the job arrival date of job *k*. Let d_k denote the due date of job *k*. Let s_k denote the start time of job *k*. Let f_k denote the finish date of job *k* (where $f_k = s_k + p_k$ -1). Let Q denote an arbitrary sequence for assigning orders. Let E_k denote earliness of job *k*. Let T_k denote tardiness of job *k*. Let α denote the unit early penalty for an early job and β denote the unit tardy penalty for a tardy job. All notations are summarized as follows:

Sets

N ： a set of *n* jobs

Q ： a set of arbitrary sequence

Parameters

a_k ： the width of job *k*

b_k ： the length of job *k*

p_k ： processing time of job *k*

r_k ： arrival date of job *k*

d_k ： due date of job *k*

α ： unit earliness penalty

β ： unit tardiness penalty

Variables

s_k ： start date of job *k* ($s_k = f_k - p_k$ +1)

f_k ： finish date of job *k*

E_k ： an earliness of job *k*

T_k ： a tardiness of job *k*

$$E_k = \text{Max}\{d_k - f_k, 0\}$$

$$T_k = \text{Max}\{f_k - d_k, 0\}$$

$f(Q)$ ： total penalty cost of Q processing sequence

The objective is to minimize the total penalty cost. That is

$$\textbf{Min} \quad f(Q) = \alpha \sum_{k=1}^{n} E_k + \beta \sum_{k=1}^{n} T_k \qquad \text{— (1)}$$

Furthermore, we assume that if a job has been completed early, the job will be moved to storage. Thus, an earliness penalty will occur. If a job has been completed late, the manufacturers have to pay a tardiness penalty for violating the contract. In function (1), α and β are unit early penalty and tardy penalty costs, respectively.

3.2 Quasi-Three-Dimensional Space Allocation Algorithm

3.2.1 Introduction

In our approach, we employ the grid system from previous researches (Perng *et al.*, 2007, 2008a, 2008b, 2008c, 2009). In the grid system, a shop floor is divided into many unit grids to represent unit areas. These grids will be the basis of our search approach.

As shown in Figure 3.2, we add the time axis to the original two-dimensional shop floor as the third axis. We call this new coordinate system as a quasi-three-dimensional space. The plane in any time unit will represent the shop floor at the time. We, therefore, will search the quasi-three dimensional space instead of two-dimensional plane in previous researches (Perng *et al.*, 2007, 2008a, 2008b, 2008c, 2009).

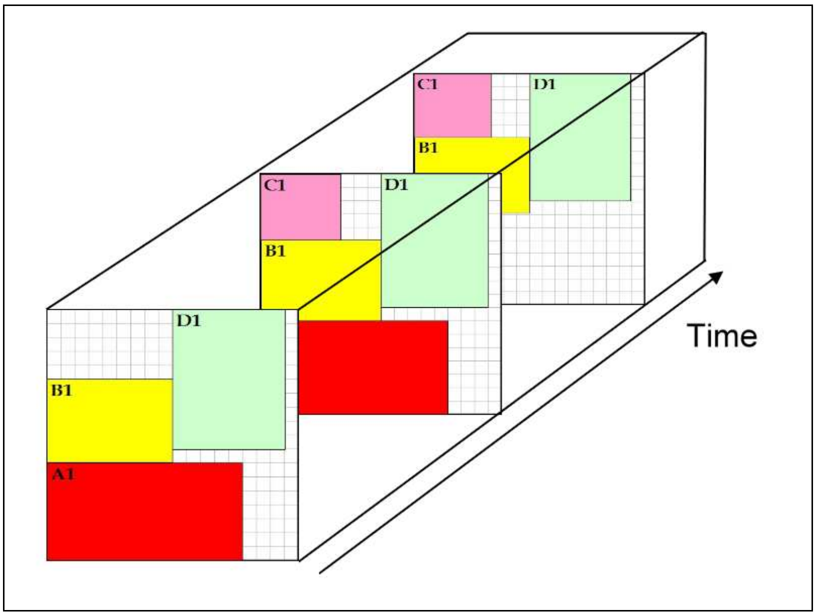

Figure 3.2 The shop floor becomes a quasi-three-dimensional space

Figure 3.3 shows an example of a space scheduling problem. Figure 3.4 and Figure 3.5 exhibit results from previous approaches and our proposed approach, respectively. Jobs are allocated into the shop floor with forward scheduling technique in Figure 3.4 while the proposed approach assigns jobs into the shop floor with backward scheduling in Figure 3.5.

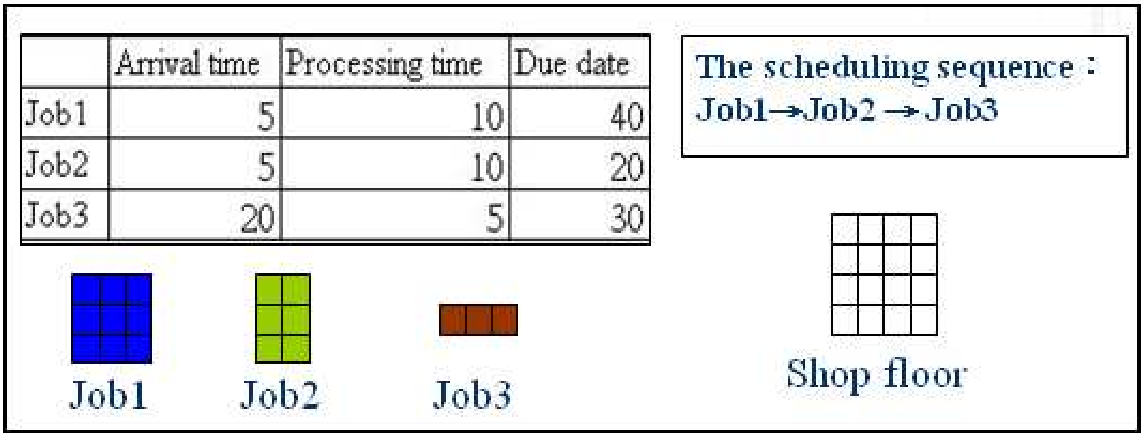

Figure 3.3 An example of a space scheduling problem

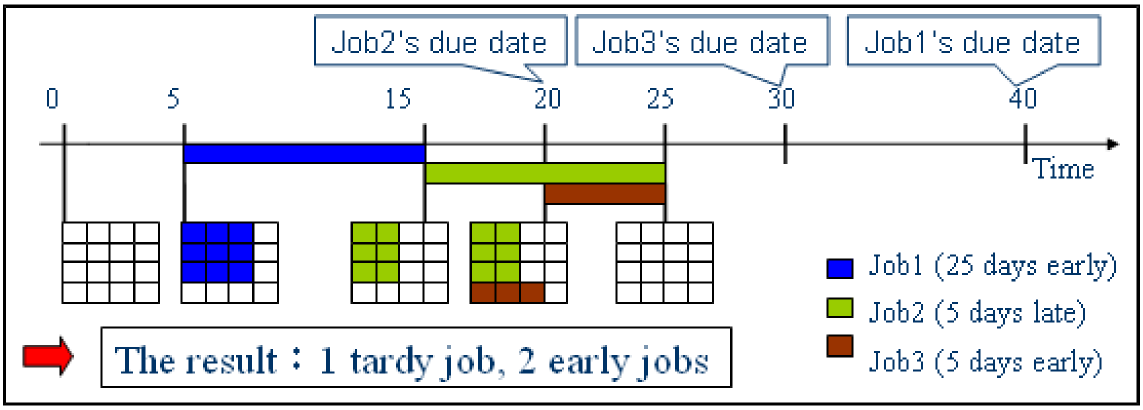

Figure 3.4 A result of two-dimensional space allocation

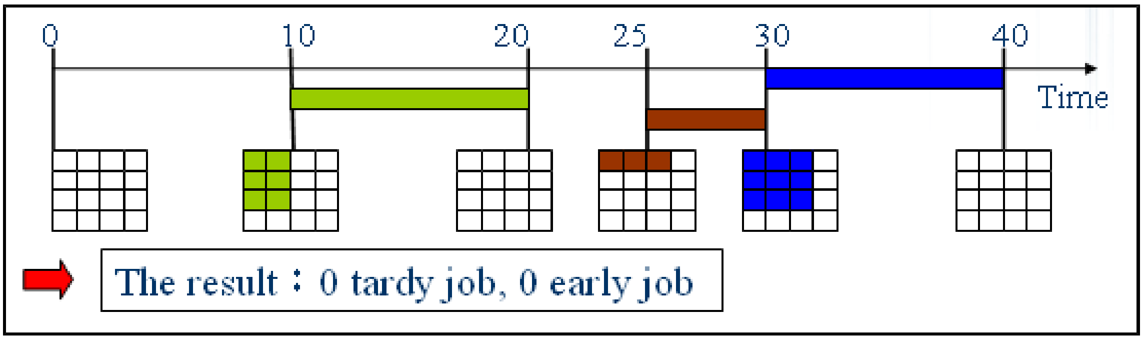

Figure 3.5 A result of quasi-three-dimensional space allocation

3.2.2 Overview of quasi-three-dimensional space allocation algorithm

A job sequence is determined by traditional dispatching rules, namely, Shortest Processing Time, Longest Processing Time, First Come First Serve, and Earliest Due Date. In addition, a space related dispatching rules, Smallest Space Requirement and Largest Space Requirement (Perng *et al.* 2007), are also included. The sequence determines the order of job allocation on the shop floor.

The Quasi-Three-Dimensional Space Allocation Algorithm (QTDSA) is based on two-dimensional space allocation approaches, such as northwest algorithm (NWA, Perng *et al.* 2007) or longest contact edge algorithm (LCEA, Perng *et al.* 2008). In the QTDSA, it is supposed that a job completing on the due date is the best scenario (a punctual case), a job completing early is the next best scenario (an early case), and the worst scenario is completed late (a tardy case). Figures 3.6 to 3.8 show a punctual case, an early case, and a tardy case, respectively.

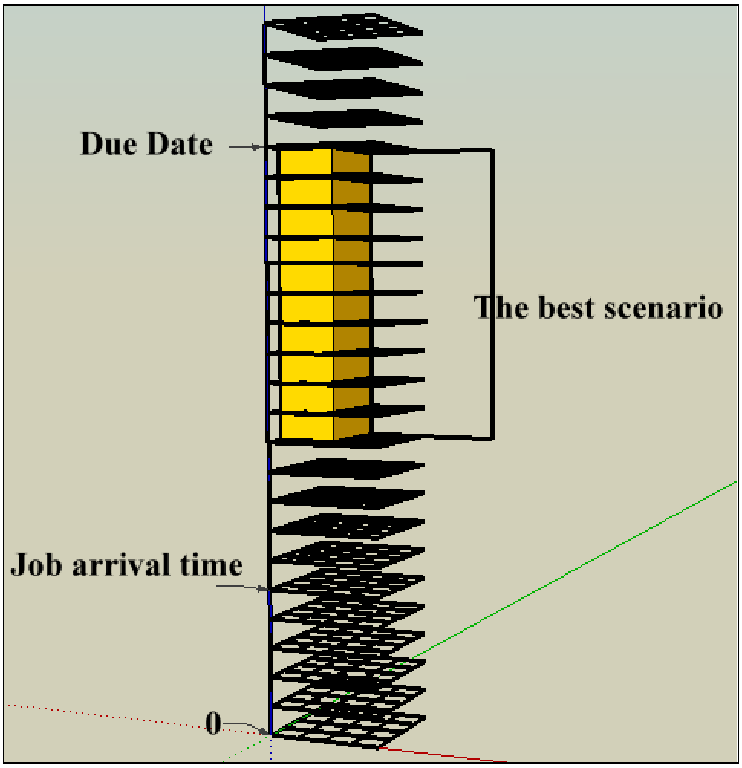

Figure 3.6 The best scenario (a punctual case)

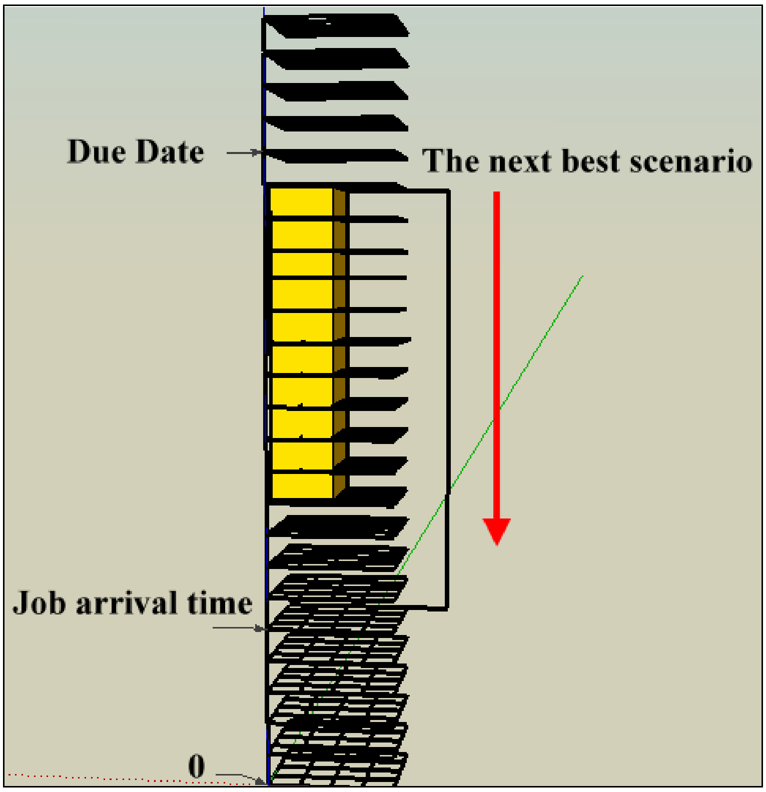

Figure 3.7 The next best scenario (an early case)

When a new job needs to be assigned on the shop floor, first, start date and finish date of the new job should be found from above three cases in proper sequence. Secondly, in order to find a plane (finish date) to contain the new job, a two-dimensional space allocation algorithm is employed for search space on the plane to determine the job's finish date, as shown in Figure 3.9. If the whole plane has no space to contain this job, new finish date of the job will be determined and a two-dimensional space allocation algorithm will be executed again until a free space is found. When the complete space is found on the start plane, this complete space will be examined between this plane and the plane of the job's start date, which equals to the due date minus the processing time of the job. If this complete space could be found, the shape of the job will be a cuboid. Figure 3.10 exhibits a cuboid shape of a job. If this cuboid does not overlap with the other cuboids previously assigned into the shop floor, the new job will be assigned to this space. If an overlap occurs like situation in Figure 3.11, the above steps will be repeated until a suitable space is found.

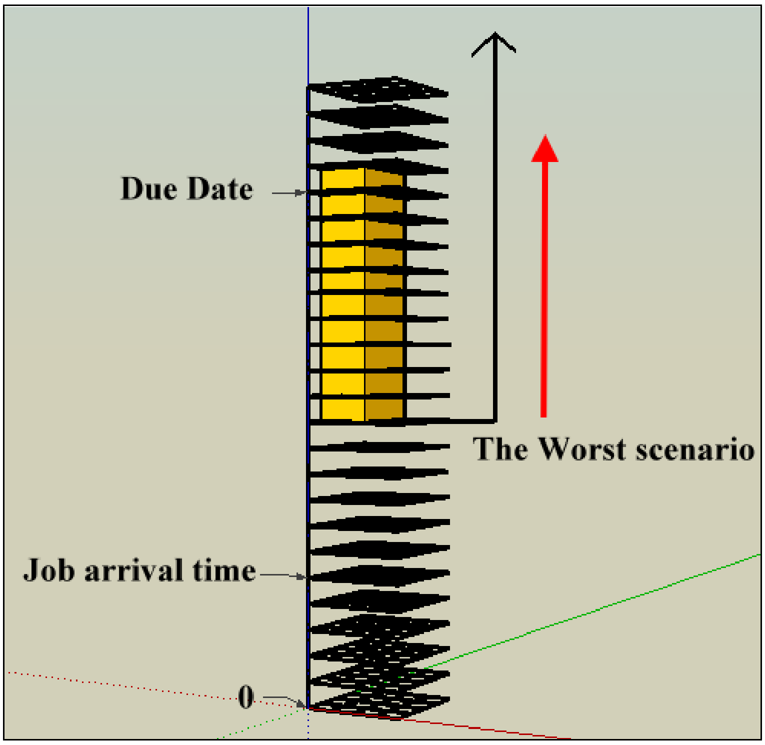

Figure 3.8 The worst scenario (a tardy case)

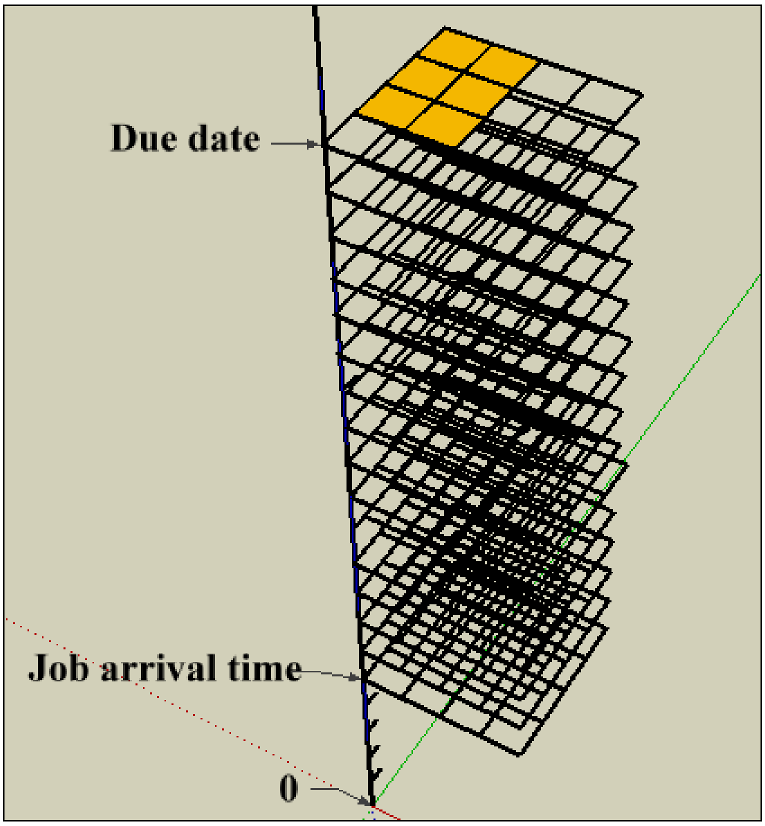

Figure 3.9 Two-dimensional Space Allocations

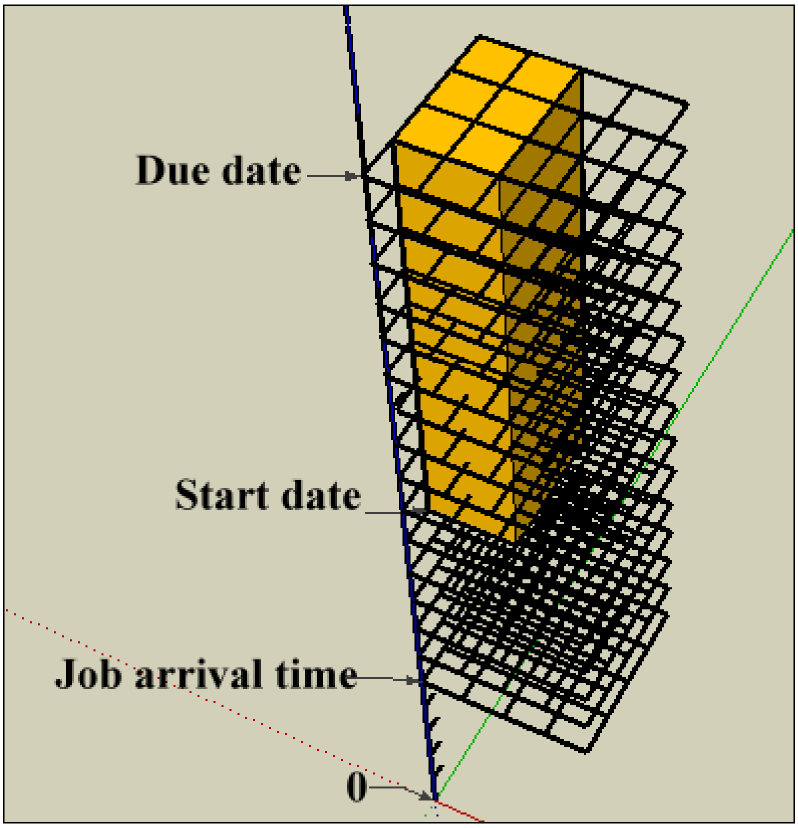

Figure 3.10 The plane of the job becomes a cuboid.

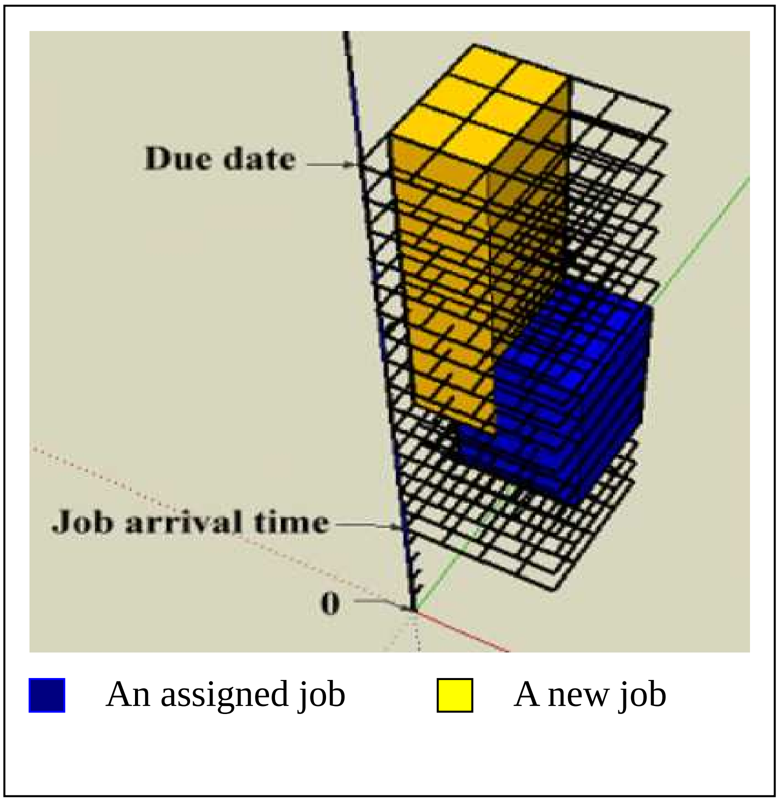

Figure 3.11 The new job overlaps with an assigned job

Figures 3.12 to 3.14 show specific rules to assign a new job into the shop floor. In the punctual case, the finish date of a new job will be the due date of the job. The start date of the job will be due date minus the processing time of the job. However, if a space can't be found to fit a new job, it will turn to the early case scenario to find a free space. In the early case, the new job's finish date (less than the due date of the new job) is used as a base line. Spaces between the base line and the arrival date of the new job will be examined. If free spaces cannot be found, it will indicate that finishing the job early will be impossible and this job will have a late completion date. Opposed to the early case, the new job's start date is used as a base line in the tardy case, and the spaces later than the base line will be examined.

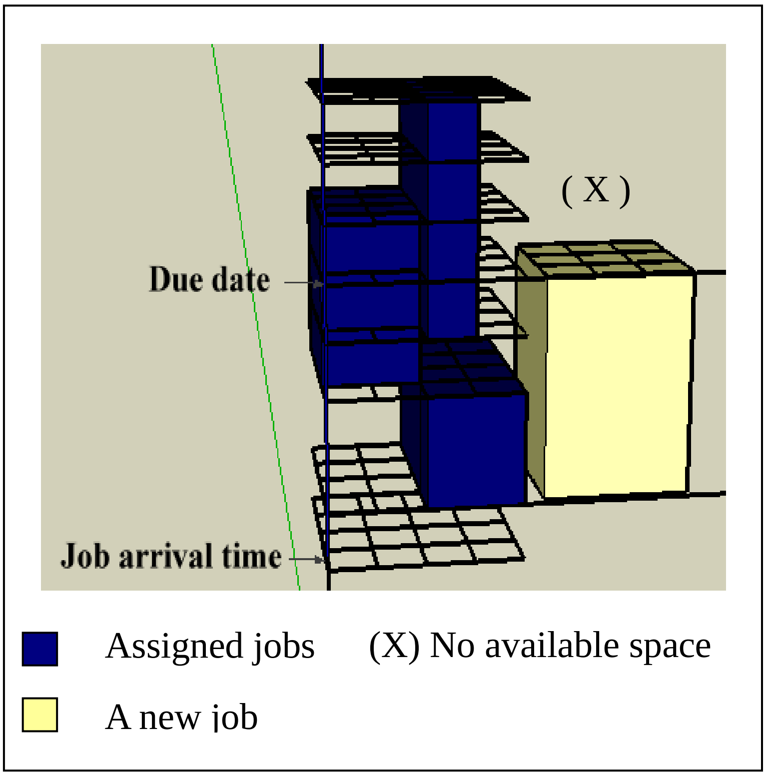

Figure 3.12 An example of a punctual case

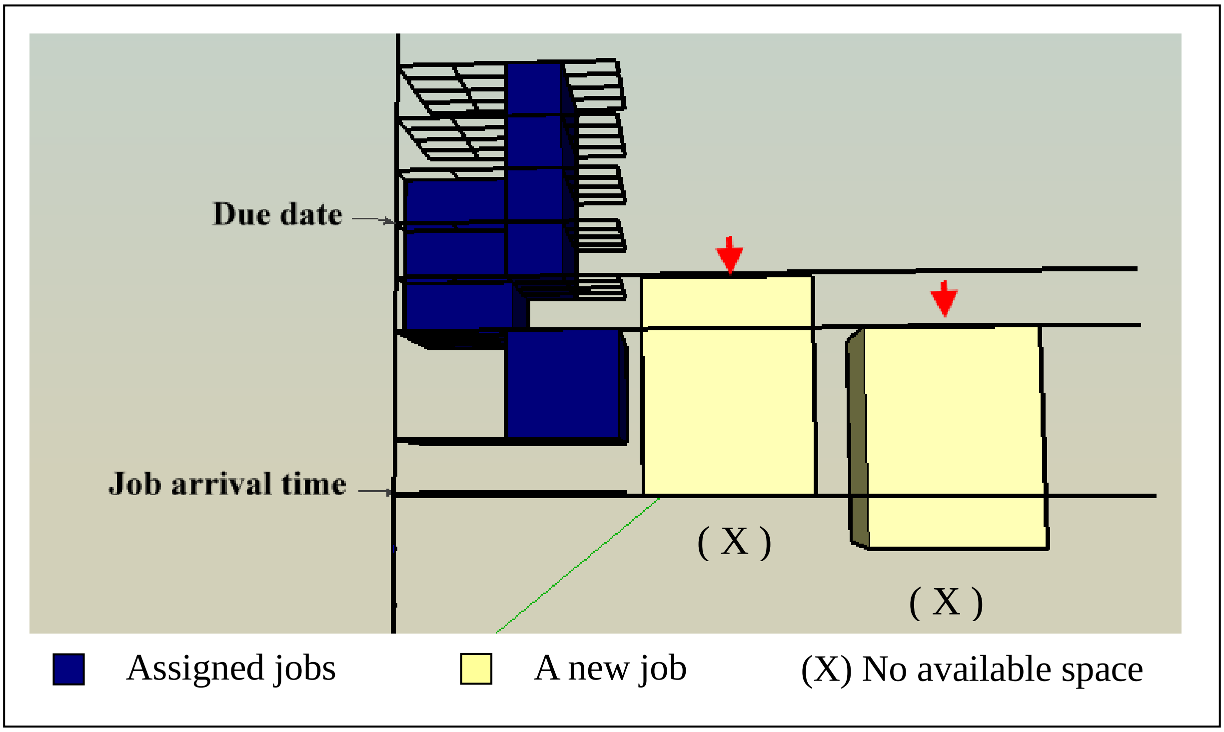

Figure 3.13 An example of an early case

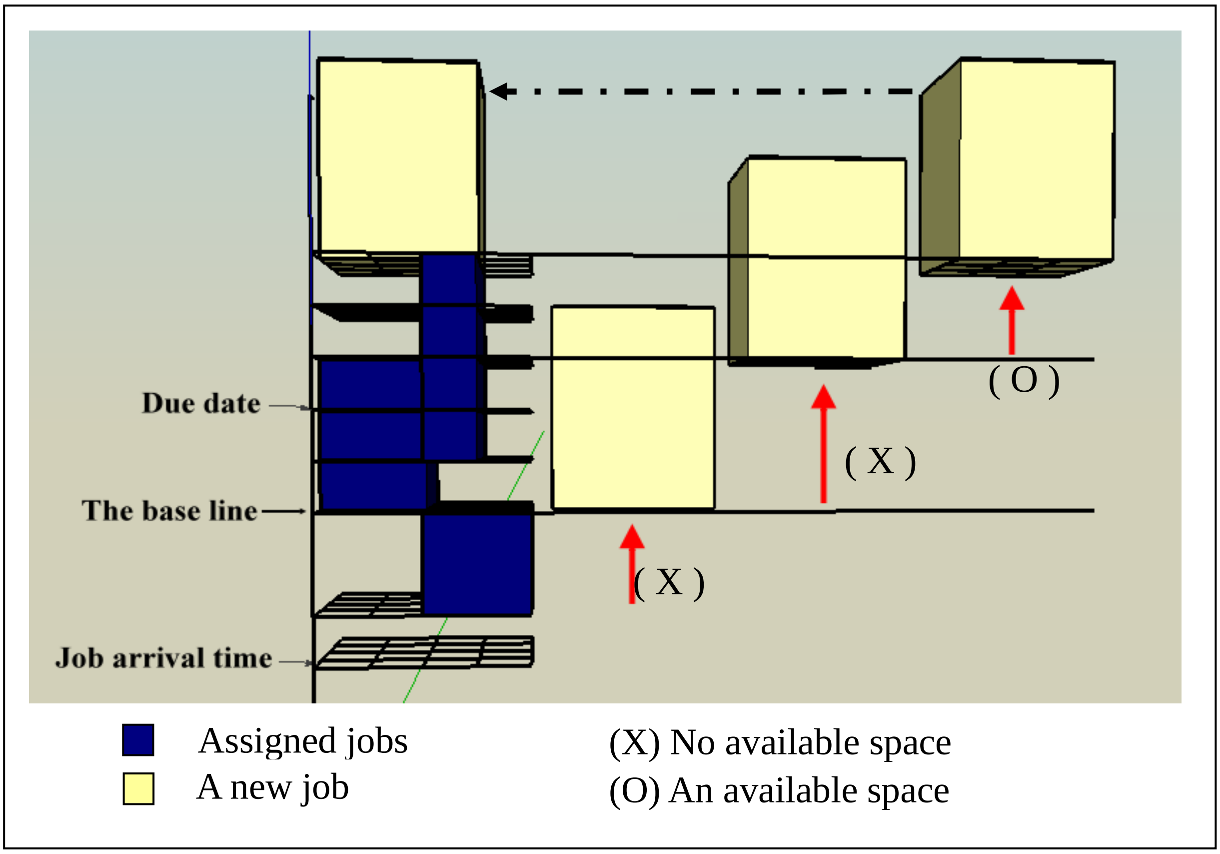

Figure 3.14 An example of a tardy case

3.2.3 The Quasi-Three-Dimensional Space Allocation Algorithm

After illustrating the concepts of QTDSA, notations, procedures, flowcharts, and pseudo code for the QTDSA are presented as follows.

Notations

Sets

T^s ：a set of dates on which the assigned jobs will start to be assembled

T^f ：a set of dates on which the assigned jobs will be finished and leave the factory

T ：a set of dates on which the layout of the factory will be changed ($T = T^s \cup T^f$)

I_k ：a set of dates obtained from T^s, and they are earlier than or equal to the due date of job *k*

O_k ：a set of dates obtained from T^f, and they are later than the latest start date of job *k*

A^J ：a set of assigned jobs

J ：a temporary set to store assigned jobs

Parameters

k ：a job number of the job which is ready to be assigned (k =*1,2,…..n*)

j ：a job number of any assigned job (j =*1,2,…..n*)

M_{IK} ：the latest date of I_k

m_{OK} ：the earliest date of O_k

L ：the length of the factory

W ：the width of the factory

Integer variables

X_k ：the X dimensional value of reference point (top left corner point) to place job *k* on the factory plane

Y_k ：the Y dimensional value of reference point to place job *k* on the factory plane

Z_k ：job *k*'s finish date

(X_k, Y_k, Z_k) : the reference point to place job k on the factory

(X, Y, Z) : any grid in the quasi-three-dimensional space

$$grid(X,Y,Z) = \begin{cases} 0, \text{ a free space of the factory plane} \\ \text{Otherwise, the space occupied by any job or obstacle} \end{cases}$$

Binary variables

$$ol_{Xkj} = \begin{cases} 1, \text{ if there is an overlap between job } k \text{ and job } j \text{ on X Dimension,} \\ 0, \text{ Otherwise.} \end{cases}$$

$$ol_{Ykj} = \begin{cases} 1, \text{ if there is an overlap between job } k \text{ and job } j \text{ on Y Dimension,} \\ 0, \text{ Otherwise.} \end{cases}$$

$$ol_{Zkj} = \begin{cases} 1, \text{ if there is an overlap between job } k \text{ and job } j \text{ on time Dimension,} \\ 0, \text{ Otherwise.} \end{cases}$$

$$rp = \begin{cases} 1, \text{ if a space is found to contain job } k \text{ on the factory on } f_k \\ 0, \text{ Otherwise.} \end{cases}$$

Procedures of the QTDSA algorithm

The steps of the QTDSA algorithm are shown below:

Step 1 : Initialization

Set $T^s = \varnothing$, $T^f = \varnothing$, and $T = \varnothing$. Obtain Q from the dispatching rule.

Step 2 : Choose the job to allocate

Choose the first job from Q and remove the job from Q. Set $f_k = d_k$.

Select the dates which are earlier than or equal to f_k from T^s to evaluate I_k.

Select the dates which are later than s_k from T^f to evaluating O_k.

Step 3 : **Load** the layout of the factory on f_k.

Step 3.1 :

If T has a value which is equal to f_k, then **go to** Step 3.2.

Otherwise, **go to** Step 3.3.

Step 3.2 :

Load the layout of the factory on f_k, then **go to** Step 4.

Step 3.3：

If T has a value which is earlier than f_k, then **go to** Step 3.4.

Otherwise, **go to** Step 3.5.

Step 3.4：

Find the maximum of the dates earlier than f_k from T

Load the layout of the factory on this date. **Go to** Step 4.

Step 3.5：

Load the initial layout of the factory. **Go to** Step 4.

Step 4： **Execute** a two-dimensional space allocation approach on the factory plane on f_k.

Set rp ＝0. In order to find a space to contain job k, the algorithm search grid (X ,Y ,Z) one by one (X =1,2,…..W ；Y =1,2,…..L ；Z = f_k) to find a reference point , if the algorithm find a space to contain job k on the factory on f_k, then rp ＝1.

Step5： Is there a space available to contain job k on the factory floor on f_k?

If rp =1, then extend the space to the plane on s_k. Find a cuboid composed of eight coordinates. Calculate the six values (X_k, Y_k, X_k+a_k, Y_k+b_k, f_k, s_k) of the coordinates and **go to** Step 6. Otherwise, **go to** Step 7.

Step 6： Are there any overlaps between job k and the assigned jobs?

Set $J = A^J$.

Step 6.1：

Select any job from J as job j. Remove it from J.

Step 6.2：Is there an overlap between job k and job j on X Dimension?

If either (1), (2) or (3) situations occur, then ol_{Xkj} =1. Otherwise, ol_{Xkj} =0.

(1)$X_k \leqq Xj \leqq X_k+a_k$

(2)$X_k \leqq X_j+a_j \leqq X_k+a_k$

(3)$X_j \leqq X_k$ and $X_j+a_j \geqq X_k+a_k$

Step 6.3：Is there an overlap between job k and job j on Y Dimension?

If either (4), (5) or (6) situations occur, then ol_{Ykj} =1. Otherwise, ol_{Ykj} =0.

(4)$Y_k \leqq Y_j \leqq Y_k+b_k$

(5)$Y_k \leqq Y_j+b_j \leqq Y_k+b_k$

(6)$Y_j \leqq Y_k$ and $Y_j+b_j \geqq Y_k+b_k$

Step 6.4：Is there an overlap between job k and job j on time dimension?

If either (7), (8) or (9) situations occur, then ol_{Zkj} =1. Otherwise, ol_{Zkj} =0.

(7) $s_k \leqq s_j \leqq f_k$

(8) $s_k \leqq f_j \leqq f_k$

(9) $s_j \leqq s_k$ and $f_j \geqq f_k$

Step 6.5：Is there an overlap between job k and job j?

If ol_{Xkj} =1, ol_{Ykj} =1 and ol_{Zkj} =1, then **go to** Step 7. Otherwise, **go to** Step 6.6.

Step 6.6：Is there any assigned job unchecked?

If $J = \varnothing$, then find an available space and **go to** Step 9.

Otherwise, **go to** Step 6.1.

Step 7： Is the whole plane on the job k's finish date searched?

If $X_k = W$, $Y_k = L$ and $Z= f_k$ then **go to** Step 8. Otherwise, **go to** Step 4.

Step 8：Redetermine new finish date to search for spaces.

Step 8.1：

If I_k is a null set, then go to Step 8.5. Otherwise, **go to** Step 8.2.

Step 8.2：

Set $f_k = M_{IK} - 1$, and remove M_{IK} from I_k.

Step 8.3：

If f_k is earlier than the earliest finish date ($r_k + p_k - 1$), in other words, s_k is earlier than r_k, then **go to** Step 8.4. Otherwise, **go to** Step 3.

Step 8.4：

Remove all elements from I_k. **Go to** Step 8.1.

Step 8.5：

Set $s_k = m_{OK}$. Calculate the value of f_k according to s_k.

Remove m_{OK} from O_k. **Go to** Step 3.

Step 9：Allocate the job k.

Add job k in A^J. Record the coordinates of job k's cuboid.

Add the dates when the layout of the factory is changed in T.

Add s_k in T^s and Add f_k+1 in T^f.

Step 10：Are there any unassigned jobs?

If $Q \neq \varnothing$, then **go to** Step2. Otherwise, all jobs are allocated to appropriate spaces.

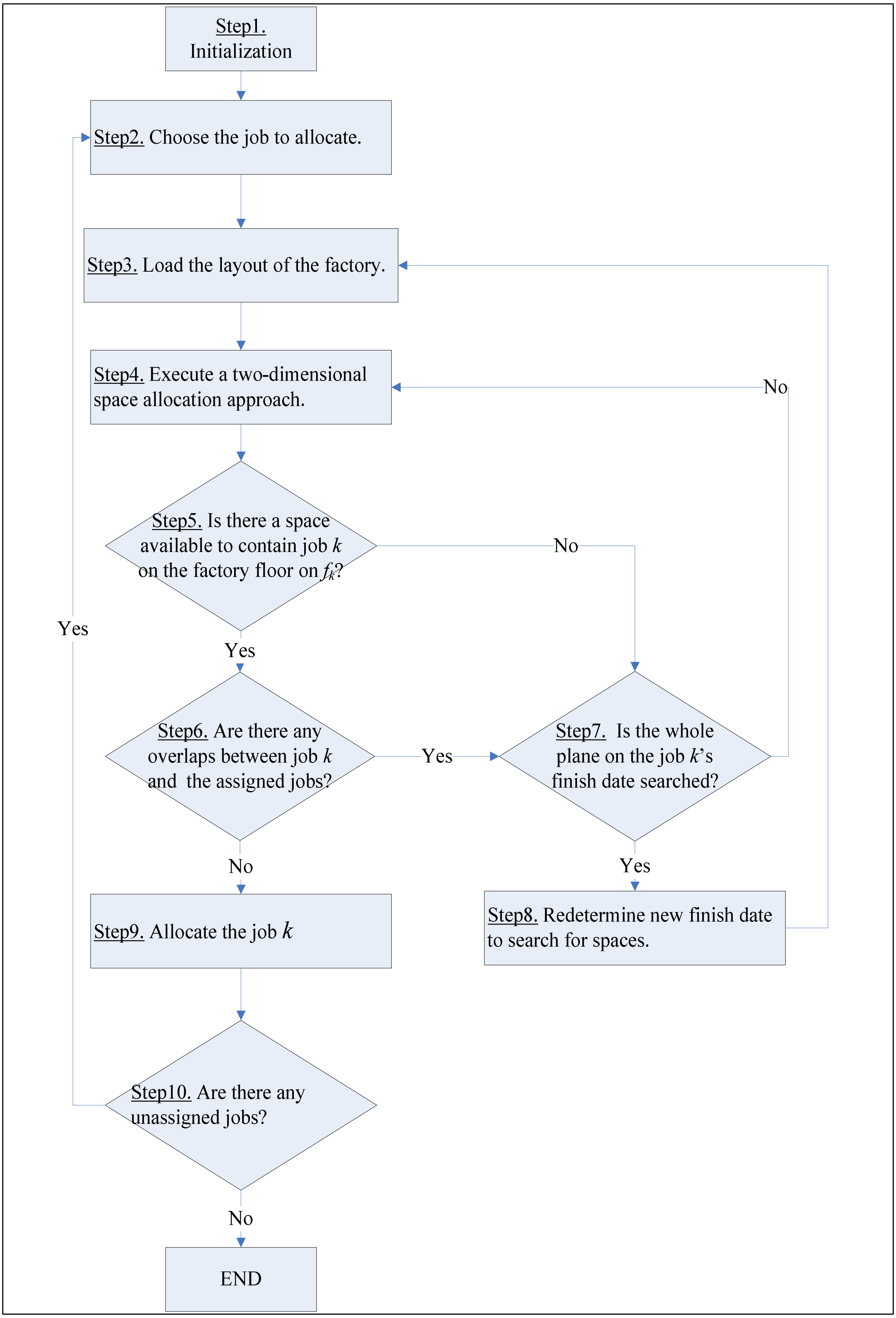

Figure 3.15 The main flowchart of the QTDSA

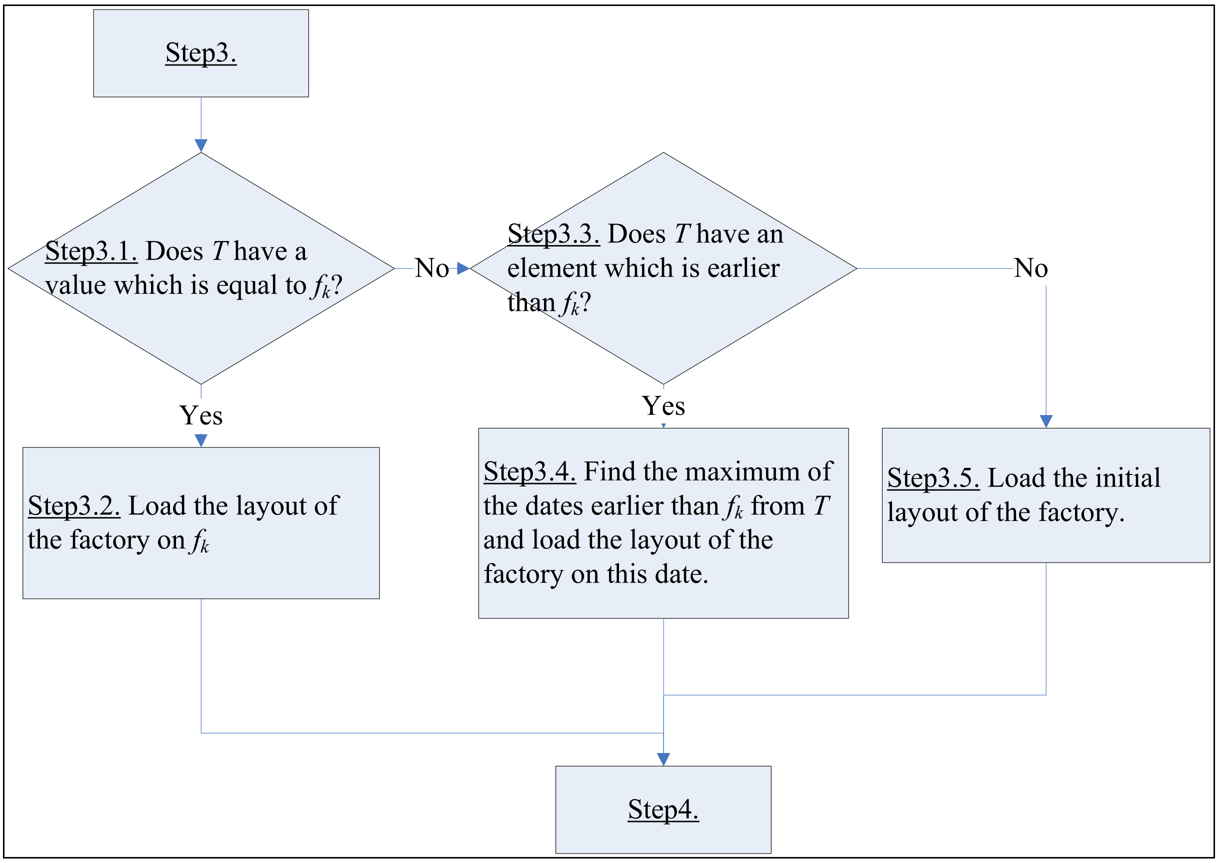

Figure 3.16 The sub-flowchart of step 3

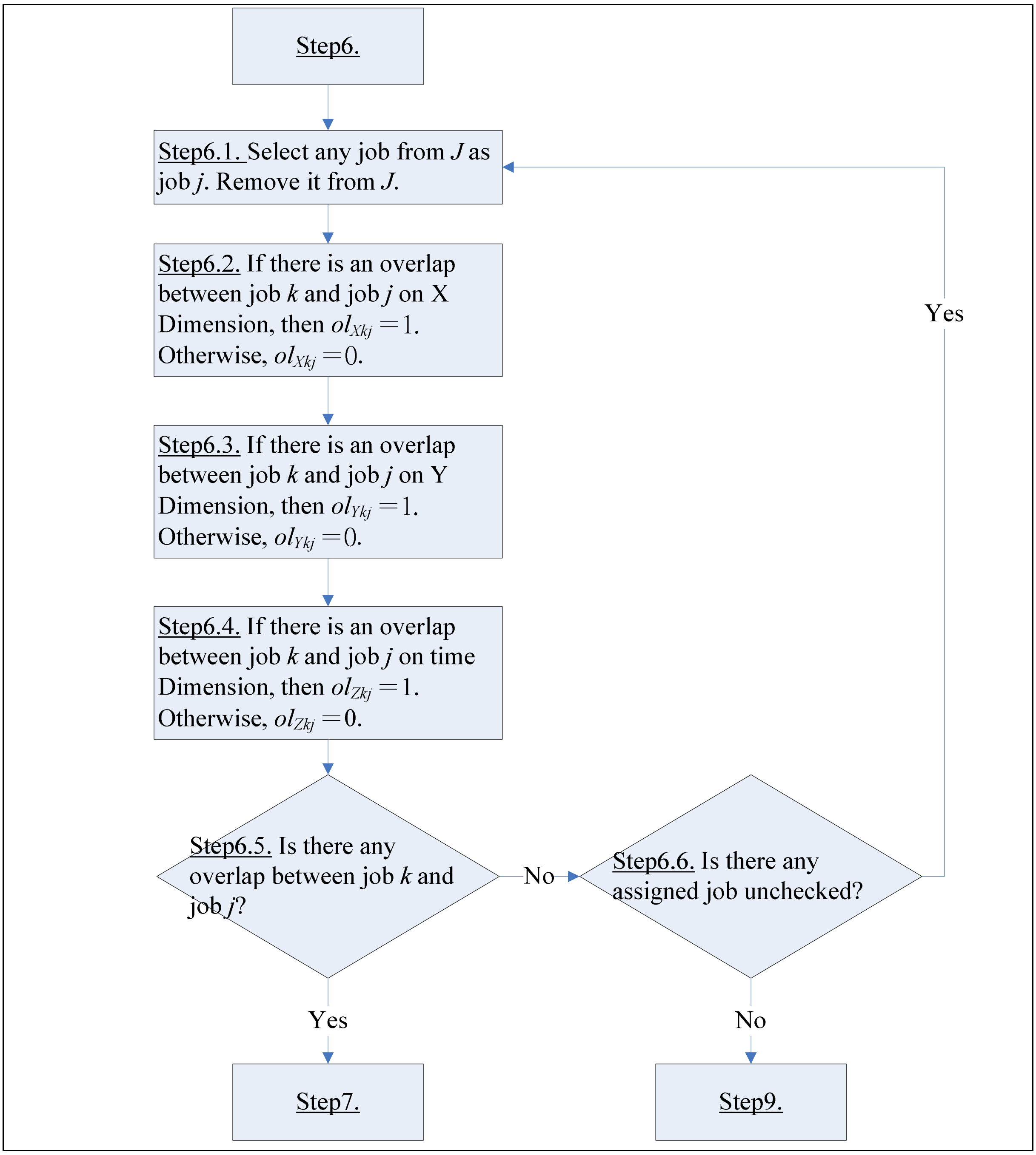

Figure 3.17 The sub-flowchart of step 6

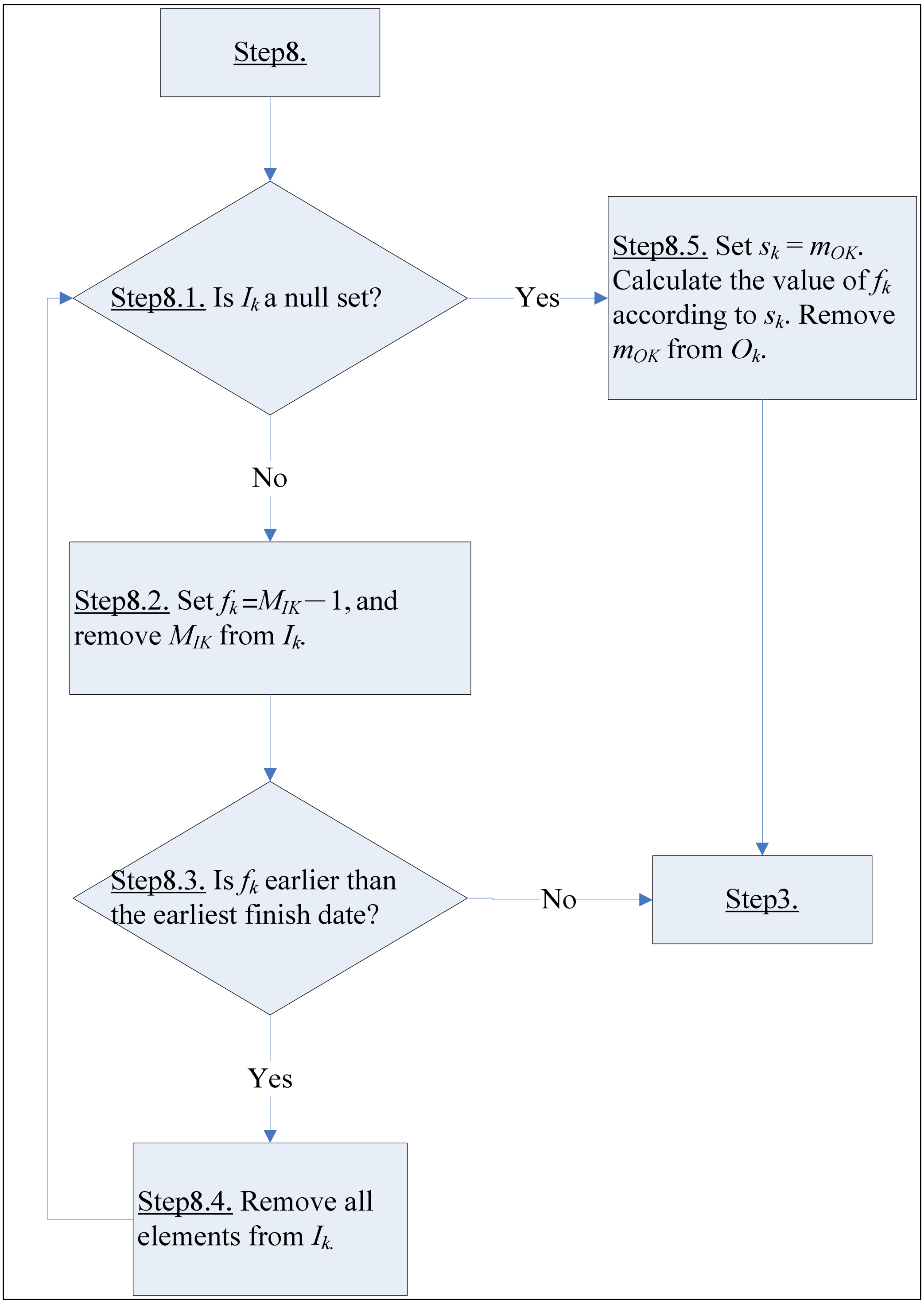

Figure 3.18 The sub-flowchart of step 8

```
Function QTDSA( )
  For number = 1 to n              // Allocate n orders
     k = Q (number)      //Choose the first job from the sequence
     f_k = d_k        //Let job k's finish date equal its due date
     find = false // If a space to contain job k is found, the variable, find, will be true.

        For i = 1 to the number of T^s      // Obtain I_k from assigned jobs'start date
           If T^s(i) <= d_k then      // The date is earlier than the latest finish time
             Add T^s(i) into I_k
           End if
        Next

        For i = 1 to the number of T^f      // Obtain O^k from assigned jobs' finish date
          If T^f(i) > f_k - p_k +1 then    // The date is later than the latest start time
           Add T^f(i) into O_k
          End if
        Next

  Call function LoadLayout (f_k)      //Load the layout of the factory
  Call function findspace      // Find a suitable space in the quasi-three-dimensional space

   If (find = false) and (I_k≠∅) then        // Early case
    fk = M_IK -1          // M_IK : the maximal element in I_k
    Remove (M_IK, I_k)        // Remove M_IK from I_k
   end if

   //When f_k is later than the earliest finish date, early case may occur.
   While (find= false) and (f_k >= r_k + p_k -1)
         Call function LoadLayout (f_k)
         Call function findspace

         If I_k ≠∅  Then
            f_k = M_IK -1
            Remove (M_IK, I_k)
         End If
   Wend

   While (find= false) and (O_k ≠∅)   //Tardy case
     s_k = m_OK        // m_OK : the minimal element in O_k
     f_k = s_k + p_k -1
         Call function LoadLayout (f_k)
         Call function findspace
         Remove (m_OK, O_k)
   Wend
  Next
End Function
```

Figure 3.19 The main function of QTDSA

```
Function LoadLayout (fk)
        If T ≠∅  Then
          For j = 1 to the number of T
            If T (j) = fk Then
                Load the layout of the factory on fk
            Else
                If T have an element which is earlier than fk then
                    Set fk = the maximum of the dates which is earlier than fk from T
                    Load the layout of the factory on fk
                Else
                    Load the initial layout of the factory
                End if
            End If
          Next
        Else
            Load the initial layout of the factory
        End If
End Function
```

Figure 3.20 The sub-function for loading the layout of the factory

```
Function findspace( )
//Execute a two-dimensional space allocation algorithm
//Search all grid on the factory
  For X = 1 to W      // W : the width of the factory
      For Y = 1 to L    // L : the length of the factory
            If (X,Y, fk) is a reference point then // (Xk, Yk, Zk):the reference point on the factory
              Call function CheckOverlap (Xk, Yk, Zk)
            End if
      Next
  Next
End Function
```

Figure 3.21 The sub-function for finding the reference point

Function CheckOverlap(X_k, Y_k, f_k)
  Let job k's coordinates value = (X_k, Y_k, X_k+a_k, Y_k+b_k, f_k, s_k)
  // a_k : the width of job k ; b_k: the length of job k

  Let *overlap* = false

    For j = 1 to the number of J
      Load job j's coordinates value (X_j, Y_j, X_j+a_j, Y_j+b_j, f_j, s_j)

      // Use the coordinates values to judge whether there is an overlap
      If there is an overlap between job k and job j on X dimension then
        ol_{Xkj} = true
      End if

      If there is an overlap between job k and job j on Y dimension then
        ol_{Ykj} = true
      End if

      If there is an overlap between job k and job j on time dimension then
        ol_{Zkj} = true
      End if

      If (ol_{Xkj} = true) and (ol_{Ykj} = true) and (ol_{Zkj} = true) then
        overlap = true
      End if
    Next

    If *overlap* = false then
      Assign job k and record data of the coordinates and the dates
      Return *find* = true
    End if
End Function

Figure 3.22 The sub-function for checking overlaps

Chapter 4 Design of Experiment

There are two experimental designs in this research. The purpose of the first experiment is to demonstrate the QTDSA outperform the previous approaches, namely, the northwest algorithm and the longest contact edge algorithm in different performance measurements. On the other hand, the second experiment tend to find the best combination of dispatching rules and space allocation algorithms for different performance measurements. In this chapter, we first present experimental data. Then, the designs of two experiments are described.

4.1 Experimental data

Data were obtained from a real company located in central Taiwan. The company has 50 orders approximately in a year. We consider three different numbers of jobs (i.e. 25, 50, and 75) in our research. The case of 25 jobs represents a situation of few orders. The case of 50 jobs represents a normal situation of job number. The case of 75 jobs represents that a large number of orders were received. The raw data of jobs were acquired from the OR-Library (Beasley, 1990, 2008) and previous research (Taillard, 1993) because real data were insufficient for overall testing. However, the job size requirements for the scheduling problem were not available in the OR-Library. The job size requirements were obtained from a company located in central Taiwan. Tables 4.1 and 4.2 show an example of a data set.

Table 4.1 An example of orders' data

Job number	Shape	Job arrival time	Processing time	Due date
1	C	5	25	30
2	B	10	40	50
3	A	10	35	50
4	D	5	35	45
5	D	5	30	40
6	B	5	20	35

Table 4.2 An example of orders' size requirements

Shape	Width	Length
A	6	6
B	4	9
C	8	5
D	7	9

Three different factories were considered in the experiments. Figure 4.1 shows the initial layouts of factories. The initial layout of factory A originated from the factory of a company located in central Taiwan. This research also hypothesized the other two factories (B and C). Their initial layouts are different from factory A.

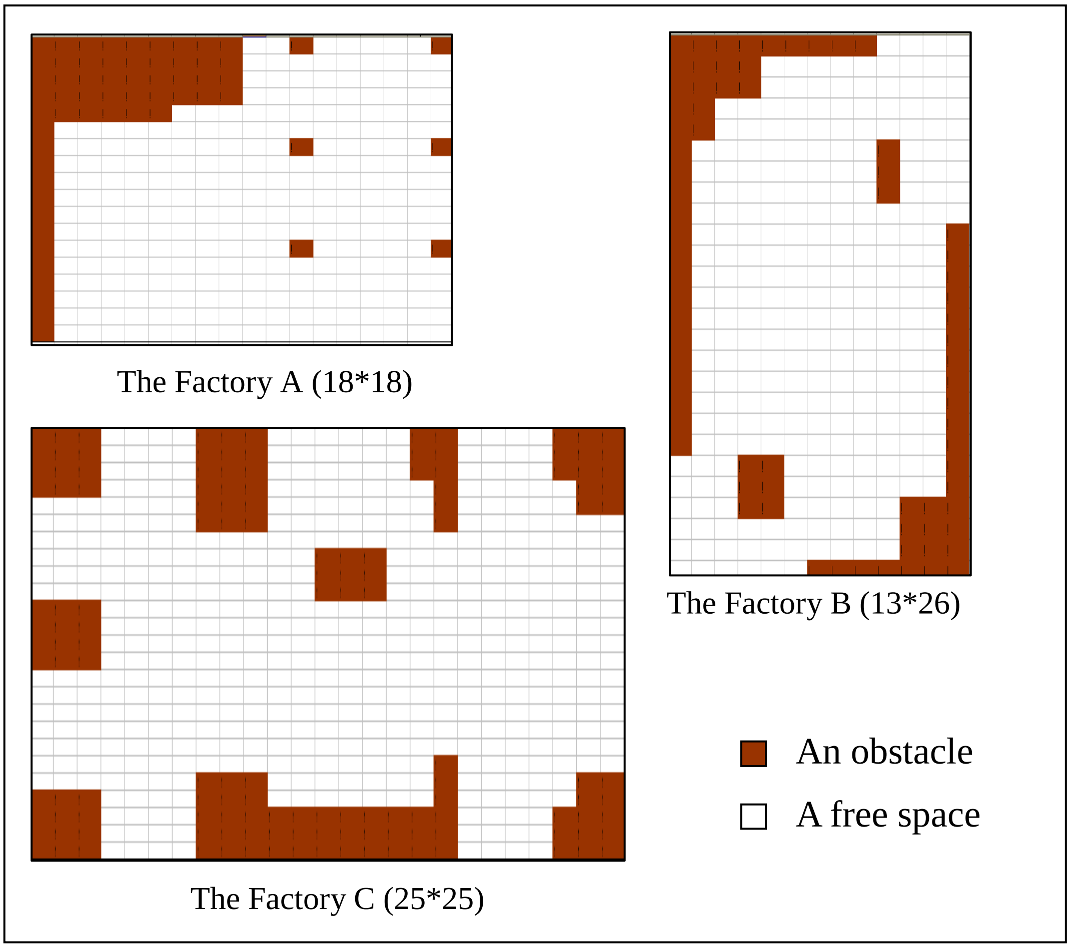

Figure 4.1 The initial layouts of factories

Six dispatching rules (SPT, LPT, FCFS, EDD, SSR and LSR) were employed to decide the sequence which determines the priorities for order allocation in this study. Two new approaches, namely, QTD-NWA and QTD-LCEA, were included in this study. QTD-NWA represents the combination of the QTDSA (three-dimensional) and the NWA (two-dimensional) algorithms. In the same way, QTD-LCEA represents the combination of the QTDSA (three-dimensional) and the LCEA (two-dimensional) algorithms. Two previous approaches, namely, the northwest algorithm and the longest contact edge algorithm were also employed in the experiments.

4.2 The First Design of Experiment

In the first experiment, the randomized block design was employed to compare QTDSA with the others space allocation approaches under different dispatching rules for each performance indicator. First, we selected twenty-seven different job sets as blocks. Nine of the job sets were 25 jobs, nine of the job sets were 50 jobs and the others were 75 jobs. The job sets which had the same number of jobs were divided into three groups. Each group had three job sets and these groups were assigned to different factories (A, B, and C) equally. Then, the independent variable in this experiment is the approach. There, there are four levels, namely, NWA, LECA, QTD-NWA, and QTD-LECA, in the experiment.

For each performance indicator, twenty-seven different job sets were allocated by different space allocation approaches using different dispatching rules. Table 4.3 shows an example of an observation table in the first experiment. It represents the observations which were obtained by different space allocation approaches using SPT rule for makespan. Two-way ANOVA with unrepeated observation was employed to analyze the observations. Because there are six dispatching rules and seven performance indicators, the first experiment should do ANOVA forty-two times. Table 4.4 shows an example of ANOVA table in the first experiment. Table 4.5 shows the hypothesis and the critical region for the first experiment.

Table 4.3 An observation table under the SPT rule for makespan

Job Set	**Approach**			
	NWA	**QTD-NWA**	**LCEA**	**QTD-LCEA**
1	45	66	45	78
2	50	75	48	75
3	86	117	86	133
4	105	107	80	112
5	197	190	172	174
6	204	219	173	195
…	…	…	…	…
27	96	100	91	103

Table 4.4 An example of ANOVA table in the first experiment

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	SSB	26	MSB	f	P	1.638019
Approach	SSA	3	MSA	f_1	P_1	2.721783
Error	SSE	78	MSE			
Total	SST	107				

Table 4.5 Hypothesis and critical region in the first experiment

Hypothesis of ANOVA	H_0: $\mu_{\text{NWA}} = \mu_{\text{LCEA}} = \mu_{\text{QTD-NWA}} = \mu_{\text{QTD-LCEA}}$ H_1: Not all means are equal
Critical region	$C = \{ f_1;\, f_1 > 2.721783 \}$

4.3 The Second Design of Experiment

The second experiment tend to find the best combination of dispatching rules and space allocation algorithms for different performance measurements. The factorial design was employed for this purpose. Eighteen job sets were selected in this experiment. Six of these job sets were 25 jobs, six of these job sets were 50 jobs and the other were 75 jobs. The job sets which had the same number of jobs were divided into three groups. Each group had two job sets, and these groups were assigned to different factories (A, B, and C) equally. In this experiment, the two factors are the dispatching rule and the approach, respectively.

Table 4.6 shows an example of an observation table in the second experiment. It represents the observations which were obtained by combination of different space allocation approaches and dispatching rules for makespan.

The second design of experiment acquired the observation under different treatment combinations repeatedly. We employed two-way ANOVA with repeated observation to analyze the observations. Table 4.7 shows an example of ANOVA table in the second experiment. Table 4.8 shows the hypotheses and the critical regions in the second experiment.

Table 4.6 An observation table for makespan

Rule	**Approach**			
	NWA	**QTDNWA**	**LCEA**	**QTDLCEA**
SPT	102	115	108	113
	146	113	135	113
	104	110	109	105
	147	145	133	136
	…	…	…	…
LPT	77	92	69	98
	121	86	86	128
	91	93	105	93
	124	105	116	102
	…	…	…	…
FCFS	98	110	96	107
	128	96	108	112
	106	113	96	104
	124	124	115	121
	…	…	…	…
EDD	81	100	105	106
	110	117	126	106
	107	99	110	99
	132	110	142	104
	…	…	…	…
SSR	102	103	103	123
	149	153	128	142
	114	137	117	127
	152	167	128	136
	….	…	…	…
LSR	85	98	85	85
	122	89	110	89
	96	99	88	91
	126	107	132	120
	…	…	…	…

Table 4.7 An example of ANOVA table in the second experiment

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Rule	SSR	5	MSR	f_1	p_1	2.236109
Approach	SSA	3	MSA	f_2	p_2	2.626775
Interaction	SS(R*A)	15	MS(R*A)	f_3	p_3	1.690951
Error	SSE	408	MSE			
Total	SST	431				

Table 4.8 Hypothesis and critical region in the second experiment

Hypothesis of ANOVA	(1) H_0: $\mu_{NWA} = \mu_{LCEA} = \mu_{QTD\text{-}NWA} = \mu_{QTD\text{-}LCEA}$ H_1: Not all means are equal (2) H_0: $\mu_{SPT} = \mu_{LPT} = \mu_{FCFS} = \mu_{EDD} = \mu_{SSR} = \mu_{LSR}$ H_1: Not all means are equal (3) H_0: The interaction is significant H_1: The interaction is not significant
Critical Region	(1) $C = \{ f_1; f_1 > 2.236109 \}$ (2) $C = \{ f_2; f_2 > 2.626775 \}$ (3) $C = \{ f_3; f_3 > 1.690951 \}$

Chapter 5 Results and Discussion

The computational system of this research was developed by Microsoft Visual Basic 6.0, and the database was created by using Microsoft Excel (CSV files). The experiments were implemented by a Pentium IV (Intel Celeron CPU 2.40GHz) computer to obtain data. All calculations were at least rounded up to the second decimal place. In the experiments, ANOVA was employed to determine the significant difference between each level of factors. The level of significance in ANOVA was 0.05. In order to perform Post-Hoc comparison, Least Significant Difference (LSD) method was used.

5.1 Results of the First Experiment

According to the data obtained from the first experiment, ANOVA was used to compare the performance between the space allocation approaches under different dispatching rules for each performance indicator. Table 5.1 shows the ANOVA table for the SPT rule and total penalties. Because f_1 = 41.71085 > 2.721783, H_0 is rejected. There is a significant difference between the space allocation approaches under the SPT rule for total penalties. Table 5.2 shows the 95% confidence interval (CI) of the approaches' performances under the SPT rule for total penalties. Table 5.3 indicates that there is no significant difference between QTD-LCEA and QTD-NWA under the SPT rule for total penalties. However, they were significant better than the other approaches under the SPT rule for total penalties.

Table 5.1 ANOVA under the SPT rule for total penalties

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	1.59E+08	26	6130087	f=243.9109	2.74E-64	1.638019
Approach	3144892	3	1048297	f_1=41.71085	3.46E-16	2.721783
Error	1960334	78	25132.48			
Total	1.64E+08	107				

Table 5.2 The 95% CI under the SPT rule for total penalties

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1516.370	1455.631	1577.110
NWA	1541.963	1481.223	1602.703
QTD-LCEA	1170.667	1109.927	1231.407
QTD-NWA	1208.111	1147.371	1268.851

Table 5.3 The comparison under the SPT rule for total penalties

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-345.70*	43.147	.000
	NWA	-371.30*	43.147	.000
	QTD-NWA	-37.44	43.147	.388

(Note: * represents the mean difference is significant at the .05 level.)

Table 5.4 shows the ANOVA table under the LPT rule for total penalties. Because f_1 = 54.077622 > 2.721783, H_0 is rejected. There is a significant difference between the space allocation approaches under the LPT rule for total penalties. Table 5.5 shows the 95% confidence interval of the approaches' performances under the LPT rule for total penalties. Table 5.6 indicates that QTD-LCEA is significant better than the other approaches under the LPT rule for total penalties.

Table 5.4 ANOVA under the LPT rule for total penalties

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	3.22E+08	26	12370051	f=577.0943	1.01E-78	1.638019
Approach	3522395	3	1174132	f_1=54.77622	3.72E-19	2.721783
Error	1671935	78	21435.06			
Total	3.27E+08	107				

Table 5.5 The 95% CI under the LPT rule for total penalties

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1739.407	1683.313	1795.502
NWA	1819.000	1762.906	1875.094
QTD-LCEA	1384.407	1328.313	1440.502
QTD-NWA	1471.037	1414.943	1527.131

Table 5.6 The comparison under the LPT rule for total penalties

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-355.00*	39.847	.000
	NWA	-434.59*	39.847	.000
	QTD-NWA	-86.63*	39.847	.033

(Note: * represents the mean difference is significant at the .05 level.)

Table 5.7 shows the ANOVA table under the FCFS rule for total penalties. Because f_1 = 49.96176 > 2.721783, H_0 is rejected. There is a significant difference between the space allocation approaches under the FCFS rule for total penalties. Table 5.8 shows the 95% confidence interval of the approaches' performances under the FCFS rule for total penalties. Table 5.9 indicates that QTD-LCEA is significant better than the other approaches under the FCFS rule for total penalties.

Table 5.7 ANOVA under the FCFS rule for total penalties

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	2.35E+08	26	9035316	f=378.4228	1.24E-71	1.638019
Approach	3578698	3	1192899	f_1=49.96176	4.02E-18	2.721783
Error	1862347	78	23876.25			
Total	2.4E+08	107				

Table 5.8 The 95% CI under the FCFS rule for total penalties

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1631.037	1571.835	1690.239
NWA	1638.741	1579.538	1697.943
QTD-LCEA	1226.185	1166.983	1285.388
QTD-NWA	1330.704	1271.501	1389.906

Table 5.9 The comparison under the FCFS rule for total penalties

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-404.85*	42.055	.000
	NWA	-412.56*	42.055	.000
	QTD-NWA	-104.52*	42.055	.015

(Note: * represents the mean difference is significant at the .05 level.)

Table 5.10 shows the ANOVA table under the EDD rule for total penalties. Because f_1 = 48.74388 > 2.721783, H_0 is rejected. There is a significant difference between the space allocation approaches under the EDD rule for total penalties. Table 5.11 shows the 95% confidence interval of the approaches' performances under the EDD rule for total penalties. Table 5.12 indicates there was no significant difference between QTD-NWA and QTD-LCEA. The analytic result proves that QTD-NWA and QTD-LCEA are significant better than the other approaches under the EDD rule for total penalties.

Table 5.10 ANOVA under the EDD rule for total penalties

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	2.09E+08	26	8029501	f=297.5345	1.32E-67	1.638019
Approach	3946323	3	1315441	f_1=48.74388	7.53E-18	2.721783
Error	2104970	78	26986.79			
Total	2.15E+08	107				

Table 5.11 The 95% CI under the EDD rule for total penalties

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1529.481	1466.541	1592.422
NWA	1567.370	1504.430	1630.311
QTD-LCEA	1148.074	1085.133	1211.015
QTD-NWA	1188.148	1125.207	1251.089

Table 5.12 The comparison under the EDD rule for total penalties

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-381.41*	44.710	.000
	NWA	-419.30*	44.710	.000
	QTD-NWA	-40.07	44.710	.373

(Note: * represents the mean difference is significant at the .05 level.)

Table 5.13 shows the ANOVA table under the SSR rule for total penalties. Because f_1 = 24.88178 > 2.721783, H_0 is rejected. There is a significant difference between the space allocation approaches under the SSR rule for total penalties. Table 5.14 shows the 95% confidence interval of the approaches' performances under the SSR rule for total penalties. Table 5.15 indicates that QTD-LCEA is significant better than the other approaches under the SSR rule for total penalties.

Table 5.13 ANOVA under the SSR rule for total penalties

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	3.69E+08	26	14180809	f=505.8478	1.67E-76	1.638019
Approach	2092589	3	697529.6	f_1=24.88178	2.14E-11	2.721783
Error	2186632	78	28033.75			
Total	3.73E+08	107				

Table 5.14 The 95% CI under the SSR rule for total penalties

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1803.111	1738.961	1867.261
NWA	1905.741	1841.591	1969.891
QTD-LCEA	1525.741	1461.591	1589.891
QTD-NWA	1727.963	1663.813	1792.113

Table 5.15 The comparison under the SSR rule for total penalties

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-277.37*	45.569	.000
	NWA	-380.00*	45.569	.000
	QTD-NWA	-202.22*	45.569	.000

(Note: * represents the mean difference is significant at the .05 level.)

Table 5.16 shows the ANOVA table under the LSR rule for total penalties. Because f_1 = 16.8414 > 2.721783, H_0 is rejected. There is a significant difference between the space allocation approaches under the LSR rule for total penalties. Table 5.17 shows the 95% confidence interval of the approaches' performances under the LSR rule for total penalties. Table 5.18 indicates there is no significant difference between QTD-NWA and QTD-LCEA. The analytic result proves that QTD-NWA and QTD-LCEA are significant better than the other approaches under the LSR rule for total penalties.

Table 5.16 ANOVA under the LSR rule for total penalties

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	2.29E+08	26	8795433	f=194.121	1.72E-60	1.638019
Approach	2289202	3	763067.4	f_1=16.8414	1.58E-08	2.721783
Error	3534104	78	45309.03			
Total	2.35E+08	107				

Table 5.17 The 95% CI under the LSR rule for total penalties

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1546.815	1465.260	1628.369
NWA	1671.778	1590.223	1753.332
QTD-LCEA	1306.630	1225.075	1388.184
QTD-NWA	1362.778	1281.223	1444.332

Table 5.18 The comparison under the LSR rule for total penalties

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-240.19*	57.933	.000
	NWA	-365.15*	57.933	.000
	QTD-NWA	-56.15	57.933	.335

(Note: * represents the mean difference is significant at the .05 level.)

After finding the best approach under different dispatching rules for total penalties, the analyses for other performance Indicators could be found in Appendix A. Tables 5.19 - 25 show the mean performance measurements for different space allocation approaches and dispatching rules. Based on the results of the first experiment, we found that QTDSA outperforms the other algorithms for total penalties, total earliness and number of early jobs.

Table 5.19 Performances of the approaches for total penalties

Performance Indicator	**Dispatching Rule**	**Approach**			
		LCEA	**NWA**	**QTD-LCEA**	**QTD-NWA**
Total Penalties	SPT	1516.370	1541.963	**1170.667***	**1208.111***
	LPT	1739.407	1819.000	**1384.407***	1471.037
	FCFS	1631.037	1638.741	**1226.185***	1330.704
	EDD	1529.481	1567.370	**1148.074***	**1188.148***
	SSR	1803.111	1905.741	**1525.741***	1727.963
	LSR	1546.815	1671.778	**1306.630***	**1362.778***

(Note: * represent the approach is significant better than the others under the dispatching rule for total penalties.)

Table 5.20 Performances of the approaches for makespan

Performance Indicator	Dispatching Rule	Approach			
		LCEA	NWA	QTD-LCEA	QTD-NWA
Makespan	SPT	143.741	145.370	149.111	151.407
	LPT	131.926	139.667	**123.444***	130.963
	FCFS	**138.185***	**138.778***	**135.037***	145.037
	EDD	139.667	143.370	133.185	137.148
	SSR	**152.444***	159.444	168.963	181.852
	LSR	129.074	136.815	129.185	127.889

(Note: * represent the approach is significant better than the others under the dispatching rule for makespan.)

Table 5.21 Performances of the approaches for space utilization

Performance Indicator	Dispatching Rule	Approach			
		LCEA	NWA	QTD-LCEA	QTD-NWA
Space Utilization	SPT	**48.414***	**46.728***	43.181	42.514
	LPT	**52.692***	49.821	**53.826***	50.682
	FCFS	**50.151***	**48.843***	**48.105***	44.932
	EDD	49.451	47.528	49.394	48.047
	SSR	**45.972***	43.308	39.810	36.489
	LSR	53.400	50.528	50.125	50.732

(Note: * represent the approach is significant better than the others under the dispatching rule for space utilization.)

Table 5.22 Performances of the approaches for total tardiness

Performance Indicator	Dispatching Rule	Approach			
		LCEA	NWA	QTD-LCEA	QTD-NWA
Total Tardiness	SPT	**898.222***	**943.556***	1112.185	1158.222
	LPT	1296.630	1380.259	**1205.963***	1312.630
	FCFS	**1106.148***	**1126.593***	**1137.593***	1261.407
	EDD	1048.630	1096.963	1016.815	1076.556
	SSR	**1276.222***	1390.667	1442.593	1638.593
	LSR	**1041.148***	1181.296	1162.926	1213.222

(Note: * represent the approach is significant better than the others under the dispatching rule for total tardiness.)

Table 5.23 Performances of the approaches for total earliness

Performance Indicator	Dispatching Rule	Approach			
		LCEA	NWA	QTD-LCEA	QTD-NWA
Total Earliness	SPT	618.148	598.407	**58.481***	**49.889***
	LPT	442.778	438.741	**178.444***	**158.407***
	FCFS	524.889	512.148	**88.593***	**69.296***
	EDD	480.852	470.407	**131.259***	**111.593***
	SSR	526.889	515.074	**83.148***	**89.370***
	LSR	505.667	490.481	**143.704***	**149.556***

(Note: * represent the approach is significant better than the others under the dispatching rule for total earliness.)

Table 5.24 Performances of the approaches for tardy jobs

Performance Indicator	Dispatching Rule	Approach			
		LCEA	NWA	QTD-LCEA	QTD-NWA
Tardy Jobs	SPT	**19.481**	20.407	**18.556**	**18.630**
	LPT	25.444	26.148	**22.185**	**23.148**
	FCFS	22.222	22.778	**19.815**	**20.667**
	EDD	**22.259**	**22.889**	25.556	25.074
	SSR	22.630	23.407	**19.444**	20.593
	LSR	22.926	23.519	**21.148**	**21.074**

(Note: * represent the approach is significant better than the others under the dispatching rule for tardy jobs.)

Table 5.25 Performances of the approaches for early jobs

Performance Indicator	Dispatching Rule	Approach			
		LCEA	NWA	QTD-LCEA	QTD-NWA
Early Jobs	SPT	29.704	28.926	**4.852***	**5.593***
	LPT	24.963	23.963	**10.852***	**12.000***
	FCFS	27.148	26.519	**6.741***	**7.185***
	EDD	26.593	26.074	**6.519***	**7.889***
	SSR	26.815	25.852	**4.370***	**6.370***
	LSR	26.556	25.852	**10.370***	**11.185***

(Note: * represent the approach is significant better than the others under the dispatching rule for early jobs.)

5.2 Results of the Second Experiment

Table 5.26 shows the two-way ANOVA table for total penalties. Because $f_1 = 0.816677 < 2.236109$, H_0 is not rejected. There is no significant difference between the dispatching rules for total penalties. Because $f_2 = 4.104096 > 2.626775$, H_0 is rejected. There is a significant difference between the space allocation approaches for total penalties. Because $f_3 = 0.042958 < 1.690951$, H_0 is not rejected. There is no significant interaction between the approaches and the rules for total penalties. Table 5.27 shows the 95% confidence interval of the rules' performances for total penalties. Table 5.28 shows the 95% confidence interval of the approaches' performances for total penalties. Table 5.29 indicates there is no significant difference between QTD-LCEA and QTD-NWA. The analytic result proves that QTD-LCEA and QTD-NWA are significant better than the other approaches for total penalties.

Table 5.26 Two-way ANOVA for total penalties

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Rule	5597017	5	1119403	f_1=0.816677	0.538243	2.236109
Approach	16876212	3	5625404	f_2=4.104096	0.006903	2.626775
Interaction	883220.3	15	58881.35	f_3=0.042958	1	1.690951
Error	5.59E+08	408	1370681			
Total						

Table 5.27 The 95% CI of the rules' performances for total penalties

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
EDD	1343.917	1072.685	1615.148
FCFS	1474.417	1203.185	1745.648
LPT	1558.611	1287.380	1829.843
LSR	1451.139	1179.907	1722.370
SPT	1381.264	1110.032	1652.495
SSR	1686.069	1414.838	1957.301

Table 5.28 The 95% CI of the approaches' performances for total penalties

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1671.185	1449.726	1892.645
NWA	1688.620	1467.161	1910.080
QTD-LCEA	1272.056	1050.596	1493.515
QTD-NWA	1298.417	1076.957	1519.876

Table 5.29 The comparison of the approaches for total penalties

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-399.13*	159.320	.013
	NWA	-416.56*	159.320	.009
	QTD-NWA	-26.36	159.320	.869

(Note: * represents the mean difference is significant at the .05 level.)

Table 5.30 shows the two-way ANOVA table for makespan. Because f_1 = 2.011746 < 2.236109, H_0 is not rejected. There is no significant difference between the dispatching rules for makespan. Because f_2 = 0.009252 < 2.626775, H_0 is not rejected. There is no significant difference between the space allocation approaches for makespan. Because f_3 = 0.114757 < 1.690951, H_0 is not rejected. There is no significant interaction between the approaches and the rules for makespan. Table 5.31 shows the 95% confidence interval of the rules' performances for makespan. Table 5.32 shows the 95% confidence interval of the approaches' performances for makespan.

Table 5.30 Two-way ANOVA for makespan

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Rule	69206.96	5	13841.39	f_1=2.011746	0.076	2.236109
Approach	190.9722	3	63.65741	f_2=0.009252	0.998778	2.626775
Interaction	11843.39	15	789.5593	f_3=0.114757	0.999988	1.690951
Error	2807158	408	6880.289			
Total	2888399	431				

Table 5.31 The 95% CI of the rules' performances for makespan

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
EDD	146.861	127.645	166.078
FCFS	149.528	130.311	168.744
LPT	140.069	120.853	159.286
LSR	139.167	119.950	158.383
SPT	156.097	136.881	175.314
SSR	176.639	157.422	195.855

Table 5.32 The 95% CI of the approaches' performances for makespan

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	151.056	135.365	166.746
NWA	152.500	136.810	168.190
QTD-LCEA	151.269	135.578	166.959
QTD-NWA	150.750	135.060	166.440

Table 5.33 shows the two-way ANOVA table for space utilization. Because f_1 = 13.0886 > 2.236109, H_0 is rejected. There is a significant difference between the dispatching rules for space utilization. Because f_2 = 0.720182 < 2.626775, H_0 is not rejected. There is no significant difference between the space allocation approaches for space utilization. Because f_3 = 0.6662 < 1.690951, H_0 is not rejected. There is no significant interaction between the approaches and the rules for space utilization. Table 5.34 shows the 95% confidence interval of the rules' performances for space utilization. Table 5.35 shows the 95% confidence interval of the approaches' performances for space utilization. Table 5.36 indicates there is no significant difference between LSR and LPT. The analytic result proves that LSR and LPT are significant better than the other rules for space utilization.

Table 5.33 Two-way ANOVA for space utilization

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Rule	5195.843	5	1039.169	f_1=13.0886	7.86E-12	2.236109
Approach	171.5364	3	57.1788	f_2=0.720182	0.540371	2.626775
Interaction	793.3937	15	52.89292	f_3=0.6662	0.817911	1.690951
Error	32393.13	408	79.39494			
Total	38553.91	431				

Table 5.34 The 95% CI of the rules' performances for space utilization

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
EDD	44.998	42.934	47.062
FCFS	44.459	42.395	46.524
LPT	48.020	45.956	50.084
LSR	48.099	46.034	50.163
SPT	41.846	39.781	43.910
SSR	38.187	36.123	40.252

Table 5.35 The 95% CI of the approaches' performances for space utilization

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	45.216	43.531	46.902
NWA	44.426	42.741	46.112
QTD-LCEA	43.877	42.191	45.562
QTD-NWA	43.553	41.868	45.239

Table 5.36 The comparison of approaches for space utilization

Dispatching Rule		Mean Difference	Std. Error	Sig.
LSR	EDD	3.10061*	1.485064	.037
	FCFS	3.63931*	1.485064	.015
	LPT	.07874	1.485064	.958
	SPT	6.25307*	1.485064	.000
	SSR	9.91144*	1.485064	.000

(Note: * represents the mean difference is significant at the .05 level.)

Table 5.37 shows the two-way ANOVA table for total tardiness. Because $f_1 = 0.904641 < 2.236109$, H_0 is not rejected. There is no significant difference between the dispatching rules for total tardiness. Because $f_2 = 0.21059 < 2.626775$, H_0 is not rejected. There is no significant difference between the space allocation approaches for total tardiness. Because $f_3 = 0.051519 < 1.690951$, H_0 is not rejected. There is no significant interaction between the approaches and the rules for total tardiness. Table 5.38 shows the 95% confidence interval of the rules' performances for total tardiness. Table 5.39 shows the 95% confidence interval of the approaches' performances for total tardiness.

Table 5.37 Two-way ANOVA for total tardiness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Rule	5706770	5	1141354	f_1=0.904641	0.477904	2.236109
Approach	797084.2	3	265694.7	f_2=0.21059	0.889056	2.626775
Interaction	975001.2	15	65000.08	f_3=0.051519	1	1.690951
Error	5.15E+08	408	1261666			
Total	5.22E+08	431				

Table 5.38 The 95% CI of the rules' performances for total tardiness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
EDD	1001.667	741.445	1261.889
FCFS	1139.236	879.014	1399.458
LPT	1217.389	957.167	1477.611
LSR	1089.792	829.570	1350.014
SPT	1019.167	758.945	1279.389
SSR	1333.069	1072.847	1593.292

Table 5.39 The 95% CI of the approaches' performances for total tardiness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1077.630	865.159	1290.100
NWA	1107.407	894.937	1319.878
QTD-LCEA	1162.935	950.465	1375.406
QTD-NWA	1185.574	973.104	1398.045

Table 5.40 shows the two-way ANOVA table for total earliness. Because $f_1 = 0.238902 < 2.236109$, H_0 is not rejected. There is no significant difference between the dispatching rules for total earliness. Because $f_2 = 212.9357 > 2.626775$, H_0 is rejected. There is a significant difference between the space allocation approaches for total earliness. Because $f_3 = 1.060049 < 1.690951$, H_0 is not rejected. There is no significant interaction between the approaches and the rules for total earliness. Table 5.41 shows the 95% confidence interval of the rules' performances for total earliness. Table 5.42 shows the 95% confidence interval of the approaches' performances for total earliness. Table 5.43 indicates there is no significant difference between QTD-LCEA and QTD-NWA. The analytic result proves that QTD-LCEA and QTD-NWA are significant better than the other approaches for total earliness.

Table 5.40 Two-way ANOVA for total earliness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Rule	45851.32	5	9170.263	f_1=0.238902	0.945151	2.236109
Approach	24520612	3	8173537	f_2=212.9357	4.2E-83	2.626775
Interaction	610349.9	15	40690	f_3=1.060049	0.392388	1.690951
Error	15661081	408	38385			
Total	40837895	431				

Table 5.41 The 95% CI of the rules' performances for total earliness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
EDD	342.250	296.861	387.639
FCFS	335.181	289.791	380.570
LPT	341.222	295.833	386.611
LSR	361.347	315.958	406.736
SPT	362.097	316.708	407.486
SSR	353.000	307.611	398.389

Table 5.42 The 95% CI of the approaches' performances for total earliness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	593.556	556.495	630.616
NWA	581.213	544.153	618.273
QTD-LCEA	109.120	72.060	146.181
QTD-NWA	112.843	75.782	149.903

Table 5.43 The comparison of the approaches for total earliness

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-484.44*	26.661	.000
	NWA	-472.09*	26.661	.000
	QTD-NWA	-3.72	26.661	.889

(Note: * represents the mean difference is significant at the .05 level.)

Table 5.44 shows the two-way ANOVA table for tardy jobs. Because f_1 = 1.418894 < 2.236109, H_0 is not rejected. There is no significant difference between the dispatching rules for tardy jobs. Because f_2 = 0.046526 < 2.626775, H_0 is not rejected. There is no significant difference between the space allocation approaches for tardy jobs. Because f_3 = 0.075082 < 1.690951, H_0 is not rejected. There is no significant interaction between the approaches and the rules for tardy jobs. Table 5.45 shows the 95% confidence interval of the rules' performances for tardy jobs. Table 5.46 shows the 95% confidence interval of the approaches' performances for tardy jobs.

Table 5.44 Two-way ANOVA for tardy jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Rule	1252.806	5	250.5611	f_1=1.418894	0.216269	2.236109
Approach	24.64815	3	8.216049	f_2=0.046526	0.986677	2.626775
Interaction	198.8796	15	13.25864	f_3=0.075082	0.999999	1.690951
Error	72048.33	408	176.5891			
Total	73524.67	431				

Table 5.45 The 95% CI of the rules' performances for tardy jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
EDD	23.278	20.199	26.356
FCFS	20.333	17.255	23.412
LPT	23.139	20.060	26.217
LSR	21.375	18.296	24.454
SPT	18.514	15.435	21.592
SSR	20.028	16.949	23.106

Table 5.46 The 95% CI of the approaches' performances for tardy jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	21.019	18.505	23.532
NWA	21.481	18.968	23.995
QTD-LCEA	20.824	18.310	23.338
QTD-NWA	21.120	18.607	23.634

Table 5.47 shows the two-way ANOVA table for early jobs. Because f_1 = 0.428612 < 2.236109, H_0 is not rejected. There is no significant difference between the dispatching rules for early jobs. Because f_2 = 138.8638 > 2.626775, H_0 is rejected. There is a significant difference between the space allocation approaches for early jobs. Because f_3 = 0.797243 < 1.690951, H_0 is not rejected. There is no significant interaction between the approaches and the rules for early jobs. Table 5.48 shows the 95% confidence interval of the rules'

performances for early jobs. Table 5.49 shows the 95% confidence interval of the approaches' performances for early jobs. Table 5.50 indicates there is no significant difference between QTD-LCEA and QTD-NWA. The analytic result proves that QTD-LCEA and QTD-NWA are significant better than the other approaches for early jobs.

Table 5.47 Two-way ANOVA for early jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Rule	225.1574	5	45.03148	f_1=0.428612	0.828697	2.236109
Approach	43768.53	3	14589.51	f_2=138.8638	5.28E-62	2.626775
Interaction	1256.417	15	83.76111	f_3=0.797243	0.681039	1.690951
Error	42865.89	408	105.0635			
Total	88115.99	431				

Table 5.48 The 95% CI of the rules' performances for early jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
EDD	17.250	14.875	19.625
FCFS	18.014	15.639	20.389
LPT	17.458	15.084	19.833
LSR	19.403	17.028	21.777
SPT	18.306	15.931	20.680
SSR	17.542	15.167	19.916

Table 5.49 The 95% CI of the approaches' performances for early jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	28.241	26.302	30.180
NWA	27.824	25.885	29.763
QTD-LCEA	6.907	4.969	8.846
QTD-NWA	9.009	7.070	10.948

Table 5.50 The comparison of the approaches for early jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-21.33*	1.395	.000
	NWA	-20.92*	1.395	.000
	QTD-NWA	-2.10	1.395	.133

(Note: * represents the mean difference is significant at the .05 level.)

Tables 5.51 - 5.52 show the mean performance measurements of the space allocation approaches and the dispatching rules. Both experiments indicate that the QTDSA is better than the other algorithms for total penalties, total earliness and number of early jobs. The performances of the QTDSA and the other algorithms are about the same for the other performance measurements. There is no significant difference between the dispatching rules for all performance indicators except the space utilization. LPT and LSR are better than the other dispatching rules for the space utilization.

Table 5.51 Performances of the approaches for each performance indicator

Performance Indicator	**Approach**			
	LCEA	**NWA**	**QTD-LCEA**	**QTD-NWA**
Total Penalties	1671.185	1688.620	**1272.056***	**1298.417***
Makespan	151.056	152.500	151.269	150.750
Space Utilization	45.216	44.426	43.877	43.553
Total Tardiness	1077.630	1107.407	1162.935	1185.574
Total Earliness	593.556	581.213	**109.120***	**112.843***
Tardy Jobs	21.019	21.481	20.824	21.120
Early Jobs	28.241	27.824	**6.907***	**9.009***

(Note: * represent the approach is significant better than the others for each performance indicator.)

Table 5.52 Performances of the dispatching rules for each performance indicator

Performance Indicator	**Dispatching Rule**					
	EDD	**FCFS**	**LPT**	**LSR**	**SPT**	**SSR**
Total Penalties	1343.917	1474.417	1558.611	1451.139	1381.264	1686.069
Makespan	146.861	149.528	140.069	139.167	156.097	176.639
Space Utilization	44.998	44.459	**48.020***	**48.099***	41.846	38.187
Total Tardiness	1001.667	1139.236	1217.389	1089.792	1019.167	1333.069
Total Earliness	342.250	335.181	341.222	361.347	362.097	353.000
Tardy Jobs	23.278	20.333	23.139	21.375	18.514	20.028
Early Jobs	17.250	18.014	17.458	19.403	18.306	17.542

(Note: * represent the rule is significant better than the others for each performance indicator.)

5.3 Summary

Based on our experimental results, some suggestions are proposed to help manufacturers make decision for each performance measurement. Tables 5.53 - 5.59 show suggested combination of space allocation approaches and dispatching rules for each performance indicator. Table 5.60 shows suggested space allocation approaches and suggested dispatching rules for each performance indicator. Under different condition, different schemes can be used to optimize different performance measurements.

Table 5.53 Suggested combination of approaches and rules for total penalties

Performance Indicator	**Dispatching Rule**	**Suggested Approaches**
Total Penalties	SPT	QTD-LCEA , QTD-NWA
	LPT	QTD-LCEA
	FCFS	QTD-LCEA
	EDD	QTD-LCEA , QTD-NWA
	SSR	QTD-LCEA
	LSR	QTD-LCEA , QTD-NWA

Table 5.54 Suggested combination of approaches and rules for makespan

Performance Indicator	**Dispatching Rule**	**Suggested Approaches**
Makespan	SPT	All approaches
	LPT	QTD-LCEA
	FCFS	LCEA, NWA , QTD-LCEA
	EDD	All approaches
	SSR	LCEA
	LSR	All approaches

Table 5.55 Suggested combination of approaches and rules for space utilization

Performance Indicator	Dispatching Rule	Suggested Approaches
Space Utilization	SPT	LCEA, NWA
	LPT	LCEA, QTD-LCEA
	FCFS	LCEA, NWA, QTD-LCEA
	EDD	All approaches
	SSR	LCEA
	LSR	All approaches

Table 5.56 Suggested combination of approaches and rules for total tardiness

Performance Indicator	Dispatching Rule	Suggested Approaches
Total Tardiness	SPT	LCEA, NWA
	LPT	QTD-LCEA
	FCFS	LCEA, NWA, QTD-LCEA
	EDD	All approaches
	SSR	LCEA
	LSR	LCEA

Table 5.57 Suggested combination of approaches and rules for total earliness

Performance Indicator	Dispatching Rule	Suggested Approaches
Total Earliness	SPT	QTD-LCEA, QTD- NWA
	LPT	QTD-LCEA, QTD- NWA
	FCFS	QTD-LCEA, QTD- NWA
	EDD	QTD-LCEA, QTD- NWA
	SSR	QTD-LCEA, QTD- NWA
	LSR	QTD-LCEA, QTD- NWA

Table 5.58 Suggested combination of approaches and rules for tardy jobs

Performance Indicator	**Dispatching Rule**	**Suggested Approaches**
Tardy Jobs	SPT	LCEA, QTD-LCEA, QTD- NWA
	LPT	QTD-LCEA, QTD- NWA
	FCFS	QTD-LCEA, QTD- NWA
	EDD	LCEA, NWA
	SSR	QTD-LCEA
	LSR	QTD-LCEA, QTD- NWA

Table 5.59 Suggested combination of approaches and rules for early jobs

Performance Indicator	**Dispatching Rule**	**Suggested Approaches**
Early Jobs	SPT	QTD-LCEA, QTD- NWA
	LPT	QTD-LCEA, QTD- NWA
	FCFS	QTD-LCEA, QTD- NWA
	EDD	QTD-LCEA, QTD- NWA
	SSR	QTD-LCEA, QTD- NWA
	LSR	QTD-LCEA, QTD- NWA

Table 5.60 Suggested schemes for different performance measurements

Performance Indicator	**Suggested Approaches**	**Suggested Rules**
Total penalties	QTD-LCEA and QTD-NWA	All rules
Makespan	All approaches	All rules
Space utilization	All approaches	LPT and LSR
Total Tardiness	All approaches	All rules
Total earliness	QTD-LCEA and QTD-NWA	All rules
Tardy jobs	QTD-LCEA and QTD-NWA	All rules
Early jobs	All approaches	All rules

Chapter 6 Conclusion and Suggestion

6.1 Conclusion

A space scheduling problem is a critical issue of work efficiency for equipment manufacturers. In this research, a new algorithm, Quasi-Three-Dimensional Space Allocation Algorithm (QTDSA), was developed to solve this problem. In the experiments, it was proved that QTDSA is more effective than the other space allocation algorithms previously developed to reduce the total penalties. The QTDSA also had better performances than the other algorithms for some other performance indicators (number of early jobs and total earliness). In addition, the performance of the QTDSA and the other algorithms were about the same for the other performance indicators (makespan, number of tardy jobs, total tardiness and space utilization).

The Quasi-three-dimensional space allocation algorithm has a completely new concept for a space scheduling problem. Although the QTDSA did not have an outstanding performance for all performance indicators, it did successfully reduce the total penalties.

This research focused on developing a space allocation approach. It provides a new direction to develop space allocation approaches. It also provides a new scheduling system for similar industries. Because it can generate different scheduling plans quickly, it will bring a company great benefits in terms of efficiency and cost saving.

6.2 Suggestions

In this study, the QTDSA was developed to reduce total penalties for a space scheduling problem. Several additional directions for further research are suggested as follows.

First, although the QTDSA is related to a quasi-three-dimensional space, it is still based on the two-dimensional space allocation approaches. The approaches of a quasi-three-dimensional coordinate system can replace two-dimensional space allocation approaches completely in the future research.

Second, there was no significant difference between the dispatching rules for almost all performance indicators according to the experimental results. It represent that if a new dispatching rules is developed to operate in coordination with the QTDSA for a space scheduling problem, the new scheduling rule may result better for each performance indicator.

Third, there are some assumptions in this study, namely, all of the orders are rectangles, there is no constraint for all resources except the space of a shop floor, there is no constraint on job's height, the buffer or storage is available to fit in any number or any shape of jobs, the unit earliness penalty is equal and the unit tardiness penalty is equal for all jobs. The different conclusions may be obtained if some assumptions are relaxed.

In summary, this study focused on a scheduling scheme to reduce total penalties for a space scheduling problem. The future research should refine the methodology and investigate the related topics for this problem.

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Appendix

A. The Other Analyses of the First Experiment

A.1 The Analysis for Makespan

Table A-1 ANOVA under the SPT rule for makespan

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	858938.6	26	33036.1	f=116.02	5.37E-52	1.638019
Approach	985.4074	3	328.4691	f_1=1.153556	0.332944	2.721783
Error	22210.09	78	284.7448			
Total	882134.1	107				

Table A-2 The 95% CI under the SPT rule for makespan

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	143.741	137.276	150.206
NWA	145.370	138.905	151.836
QTD-LCEA	149.111	142.646	155.576
QTD-NWA	151.407	144.942	157.873

Table A-3 ANOVA under the LPT rule for makespan

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	840169	26	32314.19	f=191.9292	2.66E-60	1.638019
Approach	3565.519	3	1188.506	f_1=7.059099	0.000293	2.721783
Error	13132.48	78	168.3651			
Total	856867	107				

Table A-4 The 95% CI under the LPT rule for makespan

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	131.926	126.954	136.897
NWA	139.667	134.695	144.638
QTD-LCEA	123.444	118.473	128.416
QTD-NWA	130.963	125.992	135.934

Table A-5 The comparison under the LPT rule for makespan

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-8.48*	3.532	.019
	NWA	-16.22*	3.532	.000
	QTD-NWA	-7.52*	3.532	.036

(Note: * represents the mean difference is significant at the .05 level.)

Table A-6 ANOVA under the FCFS rule for makespan

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	822074.7	26	31618.26	f=203.1164	3.04E-61	1.638019
Approach	1420.074	3	473.358	f_1=3.040862	0.033834	2.721783
Error	12141.93	78	155.6657			
Total	835636.7	107				

Table A-7 The 95% CI under the FCFS rule for makespan

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	138.185	133.405	142.965
NWA	138.778	133.998	143.558
QTD-LCEA	135.037	130.257	139.817
QTD-NWA	145.037	140.257	149.817

Table A-8 The comparison under the FCFS rule for makespan

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-3.15	3.396	.357
	NWA	-3.74	3.396	.274
	QTD-NWA	-10.00*	3.396	.004

(Note: * represents the mean difference is significant at the .05 level.)

Table A-9 ANOVA under the EDD rule for makespan

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	838389.1	26	32245.73	f=139.2464	5.39E-55	1.638019
Approach	1486.546	3	495.5154	f_1=2.13978	0.101922	2.721783
Error	18062.7	78	231.5731			
Total	857938.3	107				

Table A-10 The 95% CI under the EDD rule for makespan

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	139.667	133.836	145.497
NWA	143.370	137.540	149.201
QTD-LCEA	133.185	127.355	139.016
QTD-NWA	137.148	131.318	142.979

Table A-11 ANOVA under the SSR rule for makespan

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	1268392	26	48784.32	f=698.0316	6.35E-82	1.638019
Approach	13131.95	3	4377.318	f_1=62.63296	1.02E-20	2.721783
Error	5451.296	78	69.88841			
Total	1286976	107				

Table A-12 The 95% CI under the SSR rule for makespan

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	152.444	149.241	155.647
NWA	159.444	156.241	162.647
QTD-LCEA	168.963	165.760	172.166
QTD-NWA	181.852	178.649	185.055

Table A-13 The comparison under the SSR rule for makespan

Approach		Mean Difference	Std. Error	Sig.
LCEA	NWA	-7.00*	2.275	.003
	QTD-LCEA	-16.52*	2.275	.000
	QTD-NWA	-29.41*	2.275	.000

(Note: * represents the mean difference is significant at the .05 level.)

Table A-14 ANOVA under the LSR rule for makespan

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	706973.2	26	27191.28	f=67.6585	2.96E-43	1.638019
Approach	1356.074	3	452.0247	f_1=1.124747	0.344277	2.721783
Error	31347.43	78	401.8901			
Total	739676.7	107				

Table A-15 The 95% CI under the LSR rule for makespan

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	129.074	121.393	136.755
NWA	136.815	129.134	144.496
QTD-LCEA	129.185	121.504	136.866
QTD-NWA	127.889	120.208	135.570

A.2 The Analysis for Space Utilization

Table A-16 ANOVA under the SPT rule for space utilization

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	3819.997	26	146.923	f=4.979878	1.81E-08	1.638019
Approach	646.8743	3	215.6248	f_1=7.30849	0.000221	2.721783
Error	2301.259	78	29.50332			
Total	6768.13	107				

Table A-17 The 95% CI under the SPT rule for space utilization

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	48.414	46.333	50.495
NWA	46.728	44.647	48.809
QTD-LCEA	43.181	41.100	45.262
QTD-NWA	42.514	40.433	44.595

Table A-18 The comparison under the SPT rule for space utilization

Approach		Mean Difference	Std. Error	Sig.
LCEA	NWA	1.68552	1.478320	.258
	QTD-LCEA	5.23311*	1.478320	.001
	QTD-NWA	5.90022*	1.478320	.000

(Note: * represents the mean difference is significant at the .05 level.)

Table A-19 ANOVA under the LPT rule for space utilization

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	4093.413	26	157.439	f=7.829751	6.61E-13	1.638019
Approach	271.5259	3	90.50864	f_1=4.501174	0.005765	2.721783
Error	1568.407	78	20.10779			
Total	5933.347	107				

Table A-20 The 95% CI under the LPT rule for space utilization

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	52.692	50.974	54.410
NWA	49.821	48.103	51.540
QTD-LCEA	53.826	52.108	55.544
QTD-NWA	50.682	48.964	52.400

Table A-21 The comparison under the LPT rule for space utilization

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	1.13389	1.220437	.356
	NWA	4.00444*	1.220437	.002
	QTD-NWA	3.14389*	1.220437	.012

(Note: * represents the mean difference is significant at the .05 level.)

Table A-22 ANOVA under the FCFS rule for space utilization

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	4986.423	26	191.7855	f=9.996236	1.1E-15	1.638019
Approach	398.6157	3	132.8719	f_1=6.925544	0.000341	2.721783
Error	1496.49	78	19.18577			
Total	6881.529	107				

Table A-23 The 95% CI under the FCFS rule for space utilization

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	50.151	48.473	51.829
NWA	48.843	47.164	50.521
QTD-LCEA	48.105	46.427	49.784
QTD-NWA	44.932	43.253	46.610

Table A-24 The comparison under the FCFS rule for space utilization

Approach		Mean Difference	Std. Error	Sig.
LCEA	NWA	1.30859	1.192128	.276
	QTD-LCEA	2.04585	1.192128	.090
	QTD-NWA	5.21959*	1.192128	.000

(Note: * represents the mean difference is significant at the .05 level.)

Table A-25 ANOVA under the EDD rule for space utilization

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	4484.821	26	172.4931	f=6.610624	3.92E-11	1.638019
Approach	75.8835	3	25.2945	f_1=0.969386	0.411558	2.721783
Error	2035.279	78	26.09332			
Total	6595.983	107				

Table A-26 The 95% CI under the EDD rule for space utilization

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	49.451	47.494	51.408
NWA	47.528	45.571	49.485
QTD-LCEA	49.394	47.437	51.351
QTD-NWA	48.047	46.090	50.004

Table A-27 ANOVA under the SSR rule for space utilization

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	1851.505	26	71.21173	f=6.452369	6.86E-11	1.638019
Approach	1382.166	3	460.7219	f_1=41.7452	3.39E-16	2.721783
Error	860.8489	78	11.03652			
Total	4094.52	107				

Table A-28 The 95% CI under the SSR rule for space utilization

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	45.972	44.699	47.245
NWA	43.308	42.035	44.581
QTD-LCEA	39.810	38.537	41.083
QTD-NWA	36.489	35.216	37.762

Table A- 29 The comparison under the SSR rule for space utilization

Approach		Mean Difference	Std. Error	Sig.
LCEA	NWA	2.66411*	.904168	.004
	QTDLCEA	6.16189*	.904168	.000
	QTDNWA	9.48326*	.904168	.000

(Note: * represents the mean difference is significant at the .05 level.)

Table A-30 ANOVA under the LSR rule for space utilization

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	5073.747	26	195.1441	f=4.070444	8.08E-07	1.638019
Approach	179.9542	3	59.98472	f_1=1.251201	0.29702	2.721783
Error	3739.454	78	47.94172			
Total	8993.155	107				

Table A- 31 The 95% CI under the LSR rule for space utilization

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	53.400	50.747	56.053
NWA	50.528	47.875	53.181
QTD-LCEA	50.125	47.472	52.778
QTD-NWA	50.732	48.080	53.385

A.3 The Analysis for Total Tardiness

Table A-32 ANOVA under the SPT rule for total tardiness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	1.46E+08	26	5619593	f=175.6358	7.86E-59	1.638019
Approach	1296489	3	432162.9	f_1=13.5069	3.49E-07	2.721783
Error	2495666	78	31995.71			
Total	1.5E+08	107				

Table A-33 The 95% CI under the SPT rule for total tardiness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	898.222	829.689	966.756
NWA	943.556	875.022	1012.089
QTD-LCEA	1112.185	1043.652	1180.719
QTD-NWA	1158.222	1089.689	1226.756

Table A-34 The comparison under the SPT rule for total tardiness

Approach		Mean Difference	Std. Error	Sig.
LCEA	NWA	-45.33	48.683	.355
	QTD-LCEA	-213.96*	48.683	.000
	QTD-NWA	-260.00*	48.683	.000

(Note: * represents the mean difference is significant at the .05 level.)

Table A-35 ANOVA under the LPT rule for total tardiness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	3.17E+08	26	12190435	f=558.8968	3.5E-78	1.638019
Approach	417157.4	3	139052.5	f_1=6.375161	0.000639	2.721783
Error	1701305	78	21811.6			
Total	3.19E+08	107				

Table A-36 The 95% CI under the LPT rule for total tardiness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1296.630	1240.045	1353.214
NWA	1380.259	1323.674	1436.844
QTD-LCEA	1205.963	1149.378	1262.548
QTD-NWA	1312.630	1256.045	1369.214

Table A-37 The comparison under the LPT rule for total tardiness

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-90.67*	40.195	.027
	NWA	-174.30*	40.195	.000
	QTD-NWA	-106.67*	40.195	.010

(Note: * represents the mean difference is significant at the .05 level.)

Table A-38 ANOVA under the FCFS rule for total tardiness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	2.29E+08	26	8821877	f=317.1536	1.13E-68	1.638019
Approach	399183.6	3	133061.2	f_1=4.783657	0.004114	2.721783
Error	2169632	78	27815.79			
Total	2.32E+08	107				

Table A-39 The 95% CI under the FCFS rule for total tardiness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1106.148	1042.248	1170.048
NWA	1126.593	1062.692	1190.493
QTD-LCEA	1137.593	1073.692	1201.493
QTD-NWA	1261.407	1197.507	1325.308

Table A-40 The comparison under the FCFS rule for total tardiness

Approach		Mean Difference	Std. Error	Sig.
LCEA	NWA	-20.44	45.392	.654
	QTD-LCEA	-31.44	45.392	.491
	QTD-NWA	-155.26*	45.392	.001

(Note: * represents the mean difference is significant at the .05 level.)

Table A-41 ANOVA under the EDD rule for total tardiness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	2.06E+08	26	7915677	f=278.2763	1.73E-66	1.638019
Approach	98126.74	3	32708.91	f_1=1.149885	0.33437	2.721783
Error	2218740	78	28445.39			
Total	2.08E+08	107				

Table A-42 The 95% CI under the EDD rule for total tardiness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1048.630	984.010	1113.249
NWA	1096.963	1032.344	1161.582
QTD-LCEA	1016.815	952.196	1081.434
QTD-NWA	1076.556	1011.936	1141.175

Table A-43 ANOVA under the SSR rule for total tardiness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	3.65E+08	26	14020282	f=588.2502	4.83E-79	1.638019
Approach	1854012	3	618004.1	f_1=25.92965	9.76E-12	2.721783
Error	1859042	78	23833.87			
Total	3.68E+08	107				

Table A-44 The 95% CI under the SSR rule for total tardiness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1276.222	1217.072	1335.372
NWA	1390.667	1331.517	1449.816
QTD-LCEA	1442.593	1383.443	1501.742
QTD-NWA	1638.593	1579.443	1697.742

Table A-45 The comparison under the SSR rule for total tardiness

Approach		Mean Difference	Std. Error	Sig.
LCEA	NWA	-114.44*	42.018	.008
	QTD-LCEA	-166.37*	42.018	.000
	QTD-NWA	-362.37*	42.018	.000

(Note: * represents the mean difference is significant at the .05 level.)

Table A-46 ANOVA under the LSR rule for total tardiness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	2.23E+08	26	8589486	f=188.7676	5.01E-60	1.638019
Approach	458779.1	3	152926.4	f_1=3.360801	0.02289	2.721783
Error	3549230	78	45502.95			
Total	2.27E+08	107				

Table A-47 The 95% CI under the LSR rule for total tardiness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	1041.148	959.419	1122.877
NWA	1181.296	1099.567	1263.025
QTD-LCEA	1162.926	1081.197	1244.655
QTD-NWA	1213.222	1131.493	1294.951

Table A-48 The comparison under the LSR rule for total tardiness

Approach		Mean Difference	Std. Error	Sig.
LCEA	NWA	-140.15*	58.057	.018
	QTD-LCEA	-121.78*	58.057	.039
	QTD-NWA	-172.07*	58.057	.004

(Note: * represents the mean difference is significant at the .05 level.)

A.4 The Analysis for Total Earliness

Table A-49 ANOVA under the SPT rule for total earliness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	2292722	26	88181.63	f=4.062861	8.35E-07	1.638019
Approach	8295760	3	2765253	f_1=127.4057	5.61E-30	2.721783
Error	1692937	78	21704.32			
Total	12281419	107				

Table A-50 The 95% CI under the SPT rule for total earliness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	618.148	561.703	674.594
NWA	598.407	541.962	654.853
QTD-LCEA	58.481	2.036	114.927
QTD-NWA	49.889	-6.557	106.334

Table A-51 The comparison under the SPT rule for total earliness

Approach		Mean Difference	Std. Error	Sig.
QTD-NWA	LCEA	-568.26*	40.096	.000
	NWA	-548.52*	40.096	.000
	QTD-LCEA	-8.59	40.096	.831

(Note: * represents the mean difference is significant at the .05 level.)

Table A-52 ANOVA under the LPT rule for total earliness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	2023871	26	77841.2	f=6.919028	1.34E-11	1.638019
Approach	2008107	3	669369	f_1=59.49784	4.11E-20	2.721783
Error	877524	78	11250.31			
Total	4909502	107				

Table A-53 The 95% CI under the LPT rule for total earliness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	442.778	402.139	483.416
NWA	438.741	398.102	479.379
QTD-LCEA	178.444	137.806	219.083
QTD-NWA	158.407	117.769	199.046

Table A-54 The comparison under the LPT rule for total earliness

Approach		Mean Difference	Std. Error	Sig.
QTD-NWA	LCEA	-284.37*	28.868	.000
	NWA	-280.33*	28.868	.000
	QTD-LCEA	-20.04	28.868	.490

(Note: * represents the mean difference is significant at the .05 level.)

Table A-55ANOVA under the FCFS rule for total earliness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	1828967	26	70344.9	f=4.7764	4.13E-08	1.638019
Approach	5224303	3	1741434	f_1=118.2429	6.16E-29	2.721783
Error	1148753	78	14727.6			
Total	8202023	107				

Table A-56 The 95% CI under the FCFS rule for total earliness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	524.889	478.392	571.386
NWA	512.148	465.651	558.645
QTD-LCEA	88.593	42.096	135.089
QTD-NWA	69.296	22.800	115.793

Table A-57 The comparison under the FCFS rule for total earliness

Approach		Mean Difference	Std. Error	Sig.
QTD-NWA	LCEA	-455.59*	33.029	.000
	NWA	-442.85*	33.029	.000
	QTD-LCEA	-19.30	33.029	.561

(Note: * represents the mean difference is significant at the .05 level.)

Table A-58 ANOVA under the EDD rule for total earliness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	1925357	26	74052.2	f=6.734448	2.54E-11	1.638019
Approach	3394121	3	1131374	f_1=102.8893	4.9E-27	2.721783
Error	857690.5	78	10996.03			
Total	6177169	107				

Table A-59 The 95% CI under the EDD rule for total earliness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	480.852	440.675	521.029
NWA	470.407	430.231	510.584
QTD-LCEA	131.259	91.083	171.436
QTD-NWA	111.593	71.416	151.769

Table A-60 The comparison under the EDD rule for total earliness

Approach		Mean Difference	Std. Error	Sig.
QTD-NWA	LCEA	-369.26*	28.540	.000
	NWA	-358.81*	28.540	.000
	QTD-LCEA	-19.67	28.540	.493

(Note: * represents the mean difference is significant at the .05 level.)

Table A-61 ANOVA under the SSR rule for total earliness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	1858540	26	71482.3	f=4.569309	9.72E-08	1.638019
Approach	5104959	3	1701653	f_1=108.7735	8.64E-28	2.721783
Error	1220233	78	15644.01			
Total	8183731	107				

Table A-62 The 95% CI under the SSR rule for total earliness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	526.889	478.967	574.810
NWA	515.074	467.153	562.996
QTD-LCEA	83.148	35.227	131.070
QTD-NWA	89.370	41.449	137.292

Table A-63 The comparison under the SSR rule for total earliness

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-443.74*	34.041	.000
	NWA	-431.93*	34.041	.000
	QTD-NWA	-6.22	34.041	.855

(Note: * represents the mean difference is significant at the .05 level.)

Table A-64 ANOVA under the LSR rule for total earliness

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	2029827	26	78070.27	f=5.590979	1.65E-09	1.638019
Approach	3338432	3	1112811	f_1=79.69359	1.09E-23	2.721783
Error	1089162	78	13963.61			
Total	6457421	107				

Table A-65 The 95% CI under the LSR rule for total earliness

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	505.667	460.392	550.941
NWA	490.481	445.207	535.756
QTD-LCEA	143.704	98.429	188.978
QTD-NWA	149.556	104.281	194.830

Table A-66 The comparison under the LSR rule for total earliness

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-361.96*	32.161	.000
	NWA	-346.78*	32.161	.000
	QTD-NWA	-5.85	32.161	.856

(Note: * represents the mean difference is significant at the .05 level.)

A.5 The Analysis for Tardy Jobs

Table A-67 ANOVA under the SPT rule for tardy jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	15910.46	26	611.9409	f=204.1904	2.49E-61	1.638019
Approach	60.99074	3	20.33025	f_1=6.783728	0.000401	2.721783
Error	233.7593	78	2.996914			
Total	16205.21	107				

Table A-68 The 95% CI under the SPT rule for tardy jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	19.481	18.818	20.145
NWA	20.407	19.744	21.071
QTD-LCEA	18.556	17.892	19.219
QTD-NWA	18.630	17.966	19.293

Table A-69 The comparison under the SPT rule for tardy jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-.93	.471	.053
	NWA	-1.85*	.471	.000
	QTD-NWA	-.07	.471	.875

(Note: * represents the mean difference is significant at the .05 level.)

Table A-70 ANOVA under the LPT rule for tardy jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	26579.46	26	1022.287	f=126.9532	1.79E-53	1.638019
Approach	283.6574	3	94.55247	f_1=11.74205	1.99E-06	2.721783
Error	628.0926	78	8.052469			
Total	27491.21	107				

Table A-71 The 95% CI under the LPT rule for tardy jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	25.444	24.357	26.532
NWA	26.148	25.061	27.235
QTD-LCEA	22.185	21.098	23.272
QTD-NWA	23.148	22.061	24.235

Table A-72 The comparison under the LPT rule for tardy jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-3.26*	.772	.000
	NWA	-3.96*	.772	.000
	QTD-NWA	-.96	.772	.216

(Note: * represents the mean difference is significant at the .05 level.)

Table A-73 ANOVA under the FCFS rule for tardy jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	20138.19	26	774.5456	f=169.1232	3.32E-58	1.638019
Approach	151.7778	3	50.59259	f_1=11.04697	4.02E-06	2.721783
Error	357.2222	78	4.579772			
Total	20647.19	107				

Table A-74 The 95% CI under the FCFS rule for tardy jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	22.222	21.402	23.042
NWA	22.778	21.958	23.598
QTD-LCEA	19.815	18.995	20.635
QTD-NWA	20.667	19.847	21.487

Table A-75 The comparison under the FCFS rule for tardy jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-2.41*	.582	.000
	NWA	-2.96*	.582	.000
	QTD-NWA	-.85	.582	.148

(Note: * represents the mean difference is significant at the .05 level.)

Table A-76 ANOVA under the EDD rule for tardy jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	25030.17	26	962.6987	f=157.0262	5.61E-57	1.638019
Approach	211.2963	3	70.4321	f_1=11.48821	2.57E-06	2.721783
Error	478.2037	78	6.130817			
Total	25719.67	107				

Table A-77 The 95% CI under the EDD rule for tardy jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	22.259	21.311	23.208
NWA	22.889	21.940	23.838
QTD-LCEA	25.556	24.607	26.504
QTD-NWA	25.074	24.125	26.023

Table A-78 The comparison under the EDD rule for tardy jobs

Approach		Mean Difference	Std. Error	Sig.
LCEA	NWA	-.63	.674	.353
	QTD-LCEA	-3.30*	.674	.000
	QTD-NWA	-2.81*	.674	.000

(Note: * represents the mean difference is significant at the .05 level.)

Table A-79 ANOVA under the SSR rule for tardy jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	19856.96	26	763.7293	f=186.7209	7.6E-60	1.638019
Approach	268.963	3	89.65432	f_1=21.9192	2.15E-10	2.721783
Error	319.037	78	4.090218			
Total	20444.96	107				

Table A-80 The 95% CI under the SSR rule for tardy jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	22.630	21.855	23.405
NWA	23.407	22.633	24.182
QTD-LCEA	19.444	18.670	20.219
QTD-NWA	20.593	19.818	21.367

Table A-81 The comparison under the SSR rule for tardy jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-3.19*	.550	.000
	NWA	-3.96*	.550	.000
	QTD-NWA	-1.15*	.550	.040

(Note: * represents the mean difference is significant at the .05 level.)

Table A-82 ANOVA under the LSR rule for tardy jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	24656.5	26	948.3269	f=175.5528	8.01E-59	1.638019
Approach	125.1481	3	41.71605	f_1=7.72241	0.000139	2.721783
Error	421.3519	78	5.401947			
Total	25203	107				

Table A-83 The 95% CI under the LSR rule for tardy jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	22.926	22.035	23.816
NWA	23.519	22.628	24.409
QTD-LCEA	21.148	20.258	22.039
QTD-NWA	21.074	20.184	21.965

Table A-84 The comparison under the LSR rule for tardy jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-NWA	LCEA	-1.85*	.633	.004
	NWA	-2.44*	.633	.000
	QTD-LCEA	-.07	.633	.907

(Note: * represents the mean difference is significant at the .05 level.)

A.6 The Analysis for Early Jobs

Table A-85 ANOVA under the SPT rule for early jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	4643.963	26	178.614	f=4.701249	5.63E-08	1.638019
Approach	15687.81	3	5229.269	f_1=137.6381	4.55E-31	2.721783
Error	2963.444	78	37.99288			
Total	23295.21	107				

Table A-86 The 95% CI under the SPT rule for early jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	29.704	27.342	32.065
NWA	28.926	26.564	31.288
QTD-LCEA	4.852	2.490	7.213
QTD-NWA	5.593	3.231	7.954

Table A-87 The comparison under the SPT rule for early jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-24.85*	1.678	.000
	NWA	-24.07*	1.678	.000
	QTD-NWA	-.74	1.678	.660

(Note: * represents the mean difference is significant at the .05 level.)

Table A-88 ANOVA under the LPT rule for early jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	4782.167	26	183.9295	f=4.698892	5.68E-08	1.638019
Approach	4620.333	3	1540.111	f_1=39.3456	1.37E-15	2.721783
Error	3053.167	78	39.14316			
Total	12455.67	107				

Table A-89 The 95% CI under the LPT rule for early jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	24.963	22.566	27.360
NWA	23.963	21.566	26.360
QTD-LCEA	10.852	8.455	13.249
QTD-NWA	12.000	9.603	14.397

Table A-90 The comparison under the LPT rule for early jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-14.11*	1.703	.000
	NWA	-13.11*	1.703	.000
	QTD-NWA	-1.15	1.703	.502

(Note: * represents the mean difference is significant at the .05 level.)

Table A-91 ANOVA under the FCFS rule for early jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	4825.13	26	185.5819	f=5.618722	1.48E-09	1.638019
Approach	10668.47	3	3556.157	f_1=107.6671	1.19E-27	2.721783
Error	2576.278	78	33.0292			
Total	18069.88	107				

Table A-92 The 95% CI under the FCFS rule for early jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	27.148	24.946	29.350
NWA	26.519	24.317	28.720
QTD-LCEA	6.741	4.539	8.943
QTD-NWA	7.185	4.983	9.387

Table A-93 The comparison under the FCFS rule for early jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-20.41*	1.564	.000
	NWA	-19.78*	1.564	.000
	QTD-NWA	-.44	1.564	.777

(Note: * represents the mean difference is significant at the .05 level.)

Table A-94 ANOVA under the EDD rule for early jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	4831.463	26	185.8255	f=5.881712	5.49E-10	1.638019
Approach	9909.435	3	3303.145	f_1=104.5505	2.98E-27	2.721783
Error	2464.315	78	31.59378			
Total	17205.21	107				

Table A-95 The 95% CI under the EDD rule for early jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	26.593	24.439	28.746
NWA	26.074	23.921	28.228
QTD-LCEA	6.519	4.365	8.672
QTD-NWA	7.889	5.735	10.042

Table A-96 The comparison under the EDD rule for early jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-20.07*	1.530	.000
	NWA	-19.56*	1.530	.000
	QTD-NWA	-1.37	1.530	.373

(Note: * represents the mean difference is significant at the .05 level.)

Table A-97 ANOVA under the SSR rule for early jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	3668.13	26	141.0819	f=3.639084	5.39E-06	1.638019
Approach	11931.56	3	3977.185	f_1=102.588	5.37E-27	2.721783
Error	3023.944	78	38.76852			
Total	18623.63	107				

Table A-98 The 95% CI under the SSR rule for early jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	26.815	24.429	29.200
NWA	25.852	23.466	28.237
QTD-LCEA	4.370	1.985	6.756
QTD-NWA	6.370	3.985	8.756

Table A-99 The comparison under the SSR rule for early jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-22.44*	1.695	.000
	NWA	-21.48*	1.695	.000
	QTD-NWA	-2.00	1.695	.242

(Note: * represents the mean difference is significant at the .05 level.)

Table A-100 ANOVA under the LSR rule for early jobs

ANOVA						
Source	SS	df	MS	F	p value	f (critical)
Block	5841.241	26	224.6631	f=9.579973	3.5E-15	1.638019
Approach	6440.546	3	2146.849	f_1=91.54486	1.76E-25	2.721783
Error	1829.204	78	23.45133			
Total	14110.99	107				

Table A-101 The 95% CI under the LSR rule for early jobs

Approach	Average	95% Confidence Interval	
		Lower Bound	Upper Bound
LCEA	26.556	24.700	28.411
NWA	25.852	23.996	27.707
QTD-LCEA	10.370	8.515	12.226
QTD-NWA	11.185	9.330	13.041

Table A-102 The comparison under the LSR rule for early jobs

Approach		Mean Difference	Std. Error	Sig.
QTD-LCEA	LCEA	-16.19*	1.318	.000
	NWA	-15.48*	1.318	.000
	QTD-NWA	-.81	1.318	.538

(Note: * represents the mean difference is significant at the .05 level.)