AN ANALYSIS OF ORDER REVIEW / RELEASE PROBLEMS IN A JOB SHOP

A THESIS
SUBMITTED TO THE DEPARTMENT OF INDUSTRIAL ENGINEERING
AND THE INSTITUTE OF ENGINEERING AND SCIENCES
OF BILKENT UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF
MASTER OF SCIENCE

By
H. Yavuz Karapinar
June, 1995

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June, 1995

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Science.

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ABSTRACT

AN ANALYSIS OF ORDER REVIEW/RELEASE PROBLEMS IN A JOB SHOP

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M.S. in Industrial Engineering
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June, 1995

Order Review/Release (ORR) activities have mostly been ignored in past job shop research. In the majority of these studies, arriving jobs are immediately released to the shop floor without considering any information about the job and the system status. In practice, however, jobs arriving at the shop are first collected in a pool and then released periodically according to some release criterion. Although practitioners use ORR mechanisms to improve shop floor performance, researchers have found limited supports for the use of these input regulation policies. In this thesis, we reexamine the problem in a capacitated system. Specifically, we compare the performances of the ORR policies in a job shop with finite buffer capacities and material handling considerations. A new ORR mechanism is also proposed and compared with other methods.

Keywords : order review/release, job shop scheduling, simulation.

ÖZET

BİR ATÖLYE TİPİ ÜRETİM SİSTEMİNDE SİPARİŞ TARAMA VE ÜRETİME BAŞLATMA PROBLEMLERİNİN ANALİZİ

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Haziran, 1995

Atölye tipi üretim sistemlerinin incelenmesi ile ilgili geçmişte yapılan çalışmalarda sipariş tarama ve üretime başlatma safhası göz ardı edilmiştir. Bu çalışmaların çoğunda iş ve sistemin durumu hakkında hiç bir bilgi kullanılmadan üretime hemen başlanır. Fakat uygulamada sisteme gelen siparişler önce bir havuzda biriktirilir ve bazı üretime başlatma kriterleri kullanılarak üretime başlatma kararları periyodik olarak alınır. Sipariş tarama ve üretime başlatma yöntemleri, uygulayıcıları tarafından üretim sisteminin performansını arttırmak için kullanıldığı halde, araştırmacılar bu yöntemlerin yararı ile ilgili sınırlı sayıda destek bulabilmişlerdir. Bu tezde, kapasiteli bir sistem kullanılarak problem tekrar incelenmiştir. Daha açık bir ifade ile sipariş tarama ve üretime başlatma yöntemlerinin performansları kuyruk uzunlukları sınırlı ve malzeme taşıma sistemi içeren bir şistem kullanılarak karşılaştırılır. Yeni bir yöntem de önerilerek diğer yöntemler ile karşılaştırılmıştır.

Anahtar sözcükler : sipariş tarama/üretime başlatma, çizelgeleme, benzetim.

To my family

ACKNOWLEDGEMENT

I would like to express my gratitude to Assoc. Prof. İhsan Sabuncuoğlu due to his supervision, guidance, understanding and encouragement throughout the development of this thesis. I am also indepted to Assist. Prof. Selim Aktürk and Assist. Prof. Selçuk Karabatı for showing keen interest to the subject matter and accepting to read and review this thesis.

I would like to extend my deepest gratitude and thanks to my parents for their morale support and encouragement.

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Chapter 1

Introduction

In this thesis, we evaluate Order Review/Release (ORR) mechanisms under dynamic and stochastic environment. A new ORR method is also developed and compared with the existing ones. ORR is a component of the shop floor control system. It is the interface between the planning system and the shop floor. It simply controls the release of orders which have been released by the planning system to the shop floor by means of a backlog pool (Melnyk, Tan, Denzler and Fredendall [22]).

Major aim of ORR, which is a control process for the flow of orders to the shop floor, is achieving on time delivery. It determines the timing of the orders to be released. Melnyk and Ragatz [19] classified the activities of ORR into:

1. order preparation
2. review and evaluation of orders
3. load leveling

First step includes preparation of all information required for the job. In the second step the jobs that should be released are identified. Finally, the shop load is levelled. Third activity levels capacity utilization over time by smoothing out the peaks and valleys of load on workcenters.

ORR activities have mostly been ignored in past job shop research. In majority of these studies, arriving jobs are immediately released to the shop floor without considering any information about the job and the system status. In practice, however, jobs arriving at the shop are first collected in a pool and then released periodically according to some release criterion. These input control policies are used for the aim of reducing work in process (WIP), lead time and controling the congestion on the shop floor. Morton and Pentico [23] counts the following motives for not releasing raw materials to the shop floor until just before they are needed:

1. WIP on the floor incurs inventory charges at a higher rate than raw material.
2. There is limited space on the floor for WIP.
3. Obsolescence, damage and confusion cause high WIP to be expensive.

Although there are a number of studies in the literature that investigate the effectiveness of ORR mechanisms, researchers have found limited supports for the use of these input regulation policies. Indeed, the ORR research has the following paradox: Practitioners use ORR systems to improve shop floor performance. However, most of the simulation based studies have indicated that ORR mechanisms do not reduce overall lead times. These studies also showed that the most effective strategy for reducing mean tardiness and proportion tardy is to release all jobs immediately to the shop floor [22]. That is, potential benefits of ORR mechanisms have not been realized in these studies.

We reexamine this problem in a capacitated system. We use a simulation model of a job shop in which early shipments are prohibited. Our job shop model also includes a material handling system and finite buffer capacities.

This study is the first investigation of ORR mechanisms in a capacitated system. Because we believe that benefits of ORR mechanisms can easily be seen in a capacitated system with the congestion modelled explicitly. A comprehensive evaluation of ORR mechanisms is carried out in the thesis. Eight different ORR methods (four periodic and four continuous release mechanisms) are tested. A new ORR method is also proposed and compared with other policies.

First chapter is a brief introduction for the thesis. The subject is briefly explained. The objective and scope of the research is also outlined.

In Chapter 2, we present a review of the ORR literature. First we propose a classification framework and then summarize the existing studies according to this classification.

In Chapter 3, detailed information about the study is given. First, we explain the release mechanisms tested. Then the properties of our simulation model and experimental conditions are discussed in detail.

In Chapter 4, we present our computational findings. Statistical tests are also given to justify the conclusions.

In Chapter 5, we explain the proposed release mechanism. The proposed mechanism is also compared with the existing ones.

Finally in Chapter 6, we draw our overall conclusions and present further research directions. Simulation results, analysis of variance (ANOVA) tables and Duncan's multiple range results are given in the Appendix.

Chapter 2

Literature Review

In this chapter, we first prepare a classification framework. Then we briefly review the previous ORR studies in the literature using this classification scheme. At the end of this chapter, we also present our observations from this literature review.

Our classification of order review/release (ORR) mechanisms is based on the observations made by Philipoom, Malhotra and Jensen [29]. In this study, the authors classified the literature into two major areas: Load-limited order release and release mechanisms that are based on calculated release times. In this study, however, we added some more details and propose the following classification scheme:

1. Mechanisms that don't use any information about the shop status and the jobs to be released:

   (a) Immediate Release (IMR): This mechanism releases jobs to the shop as soon as the jobs arrive at the system. Most of the previous job shop research, which ignored ORR function, implicitly used this release mechanism. This release mechanism is also used as a benchmark for comparisons in the literature. Although it is a naive rule, it has shown better performances than other ORR mechanisms in some situations.

(b) Interval Release (IR): Jobs arriving at the shop are first collected in a pool and then released periodically. This seems to be more realistic mechanism because it reflects the situation where the jobs are kept for paperwork and released in batches at the beginning of day or shift.

2. Load limited order release: Jobs are released to the shop based upon the current workload in the shop. Due dates of the jobs are not considered. The mechanisms in this category can be further classified into:

   (a) Aggregate Loading (AGG): Jobs are released according to the current total load in the shop. The mechanism resembles a release valve that allows jobs to raise the existing shop load to a specified shop load level (Bobrowski and Park [5]). Total shop load can be measured in terms of total number of jobs in the shop or total amount of work in hours in the shop.

   (b) Workcenter Information Based Loading (WIBL): These mechanisms require more detailed information than Aggregate Loading. Total workload in the process routing of the jobs is considered for the release decision.

3. Release mechanisms that are based on calculated release times: These rules attempt to supply on time delivery. Release times are calculated by using expected flowtimes and job due dates. According to this approach the jobs are released to the shop at these release times regardless of the shop conditions. These mechanisms can also be classified into two:

   (a) Infinite Loading (INF): The release time of the job is calculated using the following flow time estimation;

$$R_i = D_i - F_i \tag{2.1}$$

where,

R_i = Release time of job i,

D_i = Due date of job i,

F_i = Flow time estimate of job i.

As can be noted, the shop capacity is not explicitly considered in this mechanism. However, finite loading explicitly considers the shop capacity.

(b) Finite Loading (FIN): This mechanism uses more detailed information about the jobs and the shop status. Finite loading explicitly considers available shop capacity over time and tries to match the job's machine requirements with capacity availability [5]. These mechanisms can also be classified into:

i. Forward Finite Loading (FFIN): It loads the operations of the job into available capacity for the appropriate workcenter by starting from the first operation. Release decision is based on the last operation load period and the due date. The job is released if the last operation load period is within a preset time window around the due date.

ii. Backward Finite Loading (BFIN): This mechanism attempts to fit each operation into available capacity for the appropriate workcenter, by starting with the last operation of the job and working backward from the job's due date. Release decision is based on the first operation load period and the current time. The job is released if the first operation load period is within a preset time window around the current time.

Vollmann et al. [38] discuss finite loading as an approach to shop-floor control. They grouped the approaches for filling a workcenter capacity into two;

- Vertical Loading: Workcenter capacity is filled job by job. A set of jobs is selected by the time of the loading to load next.
- Horizontal Loading: Entire job is loaded for all of its operations, then next job is considered. This approach is used in our study.

4. Release mechanisms that consider the workload level in the shop and the due dates of the jobs: These mechanisms attempt to control the workload

level in the shop and and at the same time they supply on time delivery of the jobs.

A list of the existing studies in the literature based on our classification scheme is given in Table 2.1.

In the following paragraphs we will give a brief review of these studies using the terminology defined in the classification framework.

Melnyk and Ragatz [19][20] identified four major components which influence the operation of ORR:

1. The order release pool
2. The shop floor
3. The planning system
4. The information system which links the above three components.

Relationships of the components is shown in Figure 2.1 [20].

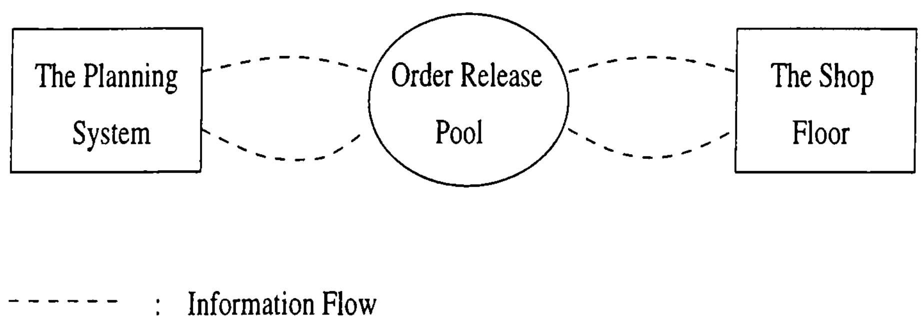

Figure 2.1: Relationships of the components

The pool includes all the orders that were released by the planning system. But these orders have not been released to the shop yet. According to these authors [20], three specifications describe a pool management system. These are:

Table 2.1: Classification of the literature

1. **Group One**:
   - **IMR**: Melnyk and Ragatz (1989); Panwalkar et al. (1976); Mahmoodi et al. (1991); Philipoom et al. (1993); Hendry and Wong (1994)
   - **IR**: Panwalkar et al. (1976); Mahmoodi et al. (1991); Melnyk et al. (1994); Melnyk et al. (1991); Bobrowski and Park (1989); Ahmed and Fisher (1992); Ragatz and Mabert (1988); Hansmann (1992)
2. **Group Two**:
   - **AGG**: Melnyk and Ragatz (1989); Melnyk et al. (1994); Melnyk et al. (1991); Bobrowski and Park (1989); Ragatz and Mabert (1988); Hendry and Wong (1994)
   - **WIBL**: Hendry and Kingsman (1991); Hendry and Wong (1994); Irastorza and Deane (1974); Melnyk and Ragatz (1989); Philipoom et al. (1993)
3. **Group Three**:
   - **INF**: Mahmoodi et al. (1991); Philipoom et al. (1993); Bobrowski and Park (1989); Park and Bobrowski (1989); Ahmed and Fisher (1992); Ragatz and Mabert (1988)
   - **FIN**:
     - **FFIN**: Bobrowski (1989); Bobrowski and Park (1989); Park and Bobrowski (1989); Ahmed and Fisher (1992)
     - **BFIN**: Ragatz and Mabert (1988)
4. **Group Four**: Hansmann (1992); Wiendahl et al. (1992); Bechte (1988); Bechte (1994); Onur and Fabrycky (1987)

- Timing Convention:
  1. Continuous
  2. Bucketed (Periodic)
- Triggering Mechanism:
  1. Shop Based
  2. Pool Based
- Selection Rule:
  1. Local
  2. Global

Timing convention determines whether the system works in a continuous or periodic basis. In the continuous case, release decisions are made any time on the time axis. In the bucketed (periodic) case, however, these decisions can only be made at the beginning of each period. Triggering mechanism determines the condition for releasing the jobs to the shop. The authors classified the triggering mechanisms into: pool based and shop based triggering mechanisms. According to the pool based triggering mechanism the release decision for a job is made using the information about that job. In the shop based case, release time is based on the current condition of the shop floor. Selection rule is used to determine the jobs to be released. The selection rules are classified as local or global selection rules. Local selection rules use only the information about the jobs in the pool. But in global rules, information about the shop status is also considered.

The planning system identifies the orders that will be released to the order release pool. The relationship between the planning system and ORR may offer an additional way to level the shop load (Melnyk and Ragatz [19]).

Melnyk and Ragatz [19] have offered a summary of the ORR literature. Their conclusion is that effective shop floor control can be achieved by controlling the release and ORR is often more important than dispatching for the users of succesfull shop floor control systems.

Melnyk and Ragatz [20] also conducted a simulation study to show the effects of ORR on the shop floor. Immediate release (IMR), an aggregate loading mechanism (AGGWNQ) and a release mechanism based on workstation loads (WCEDD) were compared. In AGGWNQ, release decision is made when the total uncompleted work in the shop falls to 180 hours. Whereas in WCEDD, release decision is made when the work in the queue at any workstation drops below 10 hours. The results indicated that AGGWNQ and WCEDD reduced both work in process (WIP) levels in the shop and the variability of the shop load. IMR showed better delivery performance than other rules. AGGWNQ and WCEDD yielded small mean flow time in the shop, but a high mean flow time in the system compared to IMR. This high mean flow time value is due to the increase in waiting times of jobs in the pool. In this study, the authors also examined the effects of a planning system which releases a constant amount of job in each period to the pool. The results showed that adding planning system improved delivery performance, but their previous conclusions did not change.

Accepting all the orders is a common assumption in the ORR literature. Philipoom and Fry [28] relaxed this assumption. The authors argued that when the congestion in the shop is high, it may be better to reject an order to allow the customer to seek another supplier, than to accept and deliver it to the customer late. They compared three acception/rejection rules by simulating a hypothetical job shop. The results of simulation experiments indicated that flow times improves as the percentage of work rejected increases. They also pointed out that shop load information should be used for the decision rather than randomly rejecting some percentage of the jobs. Their results showed that using work load information is better than random rejection in terms of mean flowtime and delivery performance. It is also observed in this study that using the information of work load at the work stations along the route of the job, rather than using the total shop load, is more effective.

Most of the job shop scheduling literature outside of ORR employ the IMR mechanism. Elvers and Taube's work [8] is among few studies that are not about ORR and use interval release (IR) for releasing jobs to the shop. In another study, Panwalkar, Smith and Dudek [25] also compared the performance of immediate release with the interval release by simulating a job shop. Interval lengths were set to 16 and 80 hours. They found that more jobs were finished early by immediate release. Larger values of the interval length caused increases in mean and variance of WIP levels. They concluded that it is better to keep the interval length small.

Mahmoodi, Dooley and Starr [18] studied the order release problem in cellular manufacturing environment. They expected that the use of order release mechanisms for cellular manufacturing cell may be very effective because load imbalance is a major disadvantage of cellular manufacturing. Immediate release, interval release and infinite loading were tested in the study. The authors used the following equation to calculate release times for infinite loading:

$$R_i = D_i - TWK_i - k * Q_i \tag{2.2}$$

where,

TWK_i = Total operation time (Total Work Content) of job i,

Q_i = Total number of jobs in queues on job i's routing,

k = planning factor.

The results of simulation experiments indicated that IMR and IR performed better than infinite loading for the mean flowtime and tardiness performances. IMR was the best rule except, when the due dates were loose. The infinite loading performed best in terms of mean lateness. Both IR and infinite loading improved the due date performance of non-due-date oriented heuristics compared to the due date oriented heuristics. Poor performances of the infinite loading are due to holding the jobs in the pool for a long time before releasing.

An evaluation of five releasing mechanisms and four dispatching rules in a job shop environment was made by Ragatz and Mabert [31]. The authors tested interval release (IR), two infinite loading methods (backward infinite loading (BIL) and modified infinite loading (MIL)), the backward finite loading (BFL) and an aggregate loading mechanism (MNJ). BIL calculates the release times using the following equation;

$$R_i = D_i - k * n_i \tag{2.3}$$

where,
n_i = number of operations of job i,
k = planning factor.
And MIL calculates the release time as follows;

$$R_i = D_i - k_1 * n_i - k_2 Q_i \tag{2.4}$$

where,
k_1, k_2 = planning factors.

MNJ, which releases the jobs to the shop floor periodically, limits the number of jobs in the shop. They evaluated the release mechanisms in terms of their total cost criteria (including delivery and inventory costs) in addition to the traditional performance measures. MIL yielded the best performance in terms of total cost while IR was the worst of all. BIL, MIL, BFL and MNJ outperformed IR in terms of shop lead time, the level of congestion in the shop and mean absolute deviation from the due dates.

Another load oriented release mechanism (PBB) was proposed by Philipoom, Malhotra and Jensen [29]. This rule was similar to the one used in [28]. In PBB, the job is released to the shop if the current load at each machine along the job's path plus the job's processing time at that machine is below the PBB treshold. In calculations, the current machine load considers the work in its queue and the work contained in the jobs which will visit the machine. Performance of PBB was compared with infinite loading mechanism (MIL) and immediate release (IMR). MIL calculates the release times with the following equation;

$$R_i = D_i - k_1 * TWK_i - k_2 * Wi \tag{2.5}$$

where,
W_i = work content of jobs along job i's route.
k_1, k_2 = planning factors.

The authors tested the rules under tight due dates and high utilization cases. Their simulation results indicated that in terms of the total cost criterion, which includes inventory and delivery costs, MIL was the best ORR policy for the loose and medium due date tightness while PBB was the best under the tight due date conditions. Whereas IMR outperformed other policies for the mean flowtime in most of the experimental conditions.

In general, the previous experimental studies showed that order release mechanisms do not improve the flowtime measure. Kanet [14] attempted to explain this by refering to the load limited order release mechanisms. He showed that limiting the load in the shop has no effect on flowtime for the M/M/1 case. He also explained the increase in the flowtime for the multi-machine case by the introduction of extra idle time into the system. Because these mechanisms require all the work, at each machine among the routing, to be less than a preset limit. So, even if a machine is out of work, it stays idle because of this requirement. This causes a decrease at the flowtime in the shop, but an increase at the flowtime in the system.

In most of the studies, the planning system component of ORR was ignored. Melnyk, Ragatz and Fredendall [21] studied the combined effect of the load smoothing made by the planning system and ORR on the job shop performance. They used IR and an aggregate loading mechanism (MAX) for releasing the jobs. In MAX, jobs are released to the shop floor until the current workload in the shop reaches a predetermined maximum load limit. It was shown that the smoothing of the load and the ORR mechanism have a complementary effect on the system performance. While the smoothing improves the mean flowtime measure, the release mechanism improves the inventory related measures. Combination of smoothing and ORR gives shorter and more consistent lead times, lower and more stable WIP values, and better delivery performances. The authors also showed that the combination of smoothing and ORR improves the performance of simple dispatching rules.

Smoothing was also considered by Melnyk, Tan, Denzler and Fredendall

[22]. They showed that smoothing the load and the reduction of variance in the processing times reduce the variance of the system. Load smoothing was achieved by keeping the weekly workloads between the 20th and 80th percentiles of the unsmoothed weekly workload distribution. Variance reduction in processing times was achieved by a change in the distribution of processing times. IR and MAX were used as in [21] for order releasing. Controlling the variances improved the effectiveness of ORR. The authors also observed that an increase in flowtime due to the MAX rule can be avoided by the controlling the variance. Also the variance control reduces the need for complex dispatching rules.

Ahmed and Fisher [1] investigated the effects of due date assignment, release and dispatching mechanisms interactions in a job shop with a simulation model. Their results showed the existence of a three-way interaction between the due date, release and dispatching mechanisms. Interaction between shop utilization and ORR policies was also found. Four release mechanisms were tested. These were IR, BIL, MIL and FFIN. BIL used Equation 2.3 for release time calculation and MIL was based on the Equation 2.4 for release date calculation. In the experiments, IR performed better than others for the flow time criterion, while BIL was best for the mean absolute deviation.

Mixed integer programming approach for the release decision were used by Irastorza and Deane [13], Onur and Fabrycky [24]. In these studies, solution modules were interfaced with their simulation models of a dynamic job shop. Irastorza and Deane's algorithm [13] attempts to balance workloads among workstations. Constraints derived from the workload assignment at each workstation are included. New jobs to be released is selected by the algorithm at the beginning of each day. Different balance measures were derived in the study. They used a bounded variable model instead of the mixed integer version in the simulation to save computer time. This means that they used a linear programming model. At the controlled shop, significant improvements were achieved in the balance measures. The algorithm also reduced the total work in the shop and the work performed for jobs in the shop values compared to the uncontrolled shop.

Onur and Fabrycky [24] proposed a combined input/output control system (DIOCS). The algorithm determines, periodically (once a week), the jobs to be released and the capacities of the workstations. It attempts to minimize the sum of underutilization, overtime, second shift, end of period workload, work in process and tardiness costs. The constraint which defines the relationship between the workload and the planned capacity is derived for each workstation. The algorithm was compared with an aggregate loading algorithm (FLCS). The results indicated that DIOCS outperformed FLCS in terms of mean tardiness, mean variance of tardiness, mean flowtime, mean variance of flow time, average WIP and total cost. FLCS was only better for the shop utilization measure.

Bobrowski and Park [5] investigated the effects of order release mechanisms on the performance of a dual constrained job shop in which early shipment is forbidden. They simulated a labor and machine limited job shop. Four release mechanisms were compared; interval release (IR), forward finite loading (FFIN), an aggregate loading mechanism (Maximum Shop Load, MSL), and an infinite loading mechanism (BIL). BIL uses Equation 2.5 for calculating the release times of the jobs. MSL releases jobs until all jobs are released or the shop load has reached a preset maximum shop load. Total cost measure, which includes inventory holding, late penalty and worker transfer costs, is used in the study. As in the case of a job shop which is not labor constrained, IR is outperformed by other release rules in terms of total cost criteria. FFIN and BIL yielded the best performance in terms of the total cost. Shop performance was kept constant, independent of due date tightness, by BIL and FFIN release mechanisms. FFIN and BIL were also better in terms of mean lateness. But IR and MSL produced better results for tardiness and proportion tardy measures.

A dual costrained job shop case was studied by Park and Bobrowski [26]. They considered three levels of labor flexibility. The degree of labor flexibility was represented as a combination of labor assignment rules and degree of worker cross-training. The release mechanisms, FFIN and BIL which were used in the study [5], were also included in the study. The results indicated that FFIN and BIL show almost the same performance under all combinations of labor flexibility and due date tightness levels. The authors used total cost criterion that includes inventory holding, late penalty and worker transfer costs.

For a shop environment where machine flexibility is available, an exchange heuristic was proposed by Bobrowski [6]. This heuristic is used after the Forward Finite Loading (FFIN) mechanism in the study. FFIN is a single pass sequential loading process. The exchange heuristic is used to improve the routing and loading of jobs prior to release to the shop. The heuristic is based on changing the order of jobs, which will be released, in the loading process. A total cost measure, which includes estimates of work in process and tardiness penalties, is used to evaluate the loading alternatives. Two types of shop flexibility was included in the study; in the first one, every primary machine was coupled with an alternate machine (ALTMAC) and in the second one, primary sequence of machines was replaced by a different sequence (ALTSEQ). The simulation results indicated that the heuristic does only show a significant improvement in the total cost for the ALTSEQ case.

Hendry and Kingsman [10] presented a load-oriented release mechanism that aims to control the shop floor throughput times. It is shown that if the released backlogs (RBLs) of all workstations are maintained between the preset limits, then it is possible to control the flow times in the shop. RBL of a workstation is the number of days to produce the jobs which are currently being processed on the shop floor. The mechanism allows capacity adjustments if necessary. The jobs are ranked in the pool according to their latest release dates. This is the latest date on which a job can be released to meet its promised delivery date. Then, the jobs which maintain the RBLs between their limits are released. When a job is released the RBL of the workstations along the route of the job is increased. It is argued that the releasing mechanism may reduce shop congestion and decrease work in process levels and the cost.

Hendry and Wong [11] coded a simplified version of the releasing rule developed by Hendry and Kingsman [10]. This load oriented release mechanism (JSSWC) was compared by the release mechanisms IMR, AGGWNQ, and WCEDD by a simulation study. AGGWNQ and WCEDD were proposed in [20] by Melnyk and Ragatz. As compared to the AGGWNQ and WCEDD mechanisms, JSSWC allows capacity adjustments. Four different versions of JSSWC were evaluated in the study. IMR gives the best results in terms of proportion tardy and mean flow time measures. JSSWC outperforms AGG-WNQ and WCEDD in terms of delivery performance and workload measures. But it is slightly worse than WCEDD under the workload balance. Workload balance is determined by the mean of the standard deviations of queue lengths. The study showed that the capacity adjustment improves the mean tardiness measure.

Bechte [3] developed a load oriented manufacturing control mechanism for job shops. The mechanism establishes realistic order due dates and performs midterm capacity planning at the order entry stage. At the order release stage, short-term capacity planning is done. Load oriented order release forms the nucleus of this mechanism. It tries to keep actual lead times on a planned level to supply on time delivery. This periodic release mechanism is formed in two steps:

1. Establish urgent orders.
2. Release workable orders.

Release dates of the jobs in the pool were calculated to identify urgent jobs. This is achieved by scheduling the orders backwards with reliable operation lead times. Jobs which have release dates in a preset time window are called urgent. Urgent jobs are ranked according to their release dates and released as long as the load limits of all workstations involved are not exceeded. The second step of the procedure has to be repeated after the capacity adjustment if the capacities can be changed. They implemented their control system in a plastic leaves factory. The mechanism reduced lead times and inventories. Lead times correspond to the times which the jobs spend in the shop. Lead times were kept on planned levels. Delivery delay was reduced and a high workcenter utilization was guaranteed. In [4], Bechte describes the principles of the load oriented manufacturing control and its implementation in a pump manufacturing company. Satisfactory results were obtained. The total lead time from order entry to delivery was reduced from 14 weeks to 9 weeks.

In another study Wiendahl, Glässner and Peterman [39] described a load oriented manufacturing control system and its industrial applications. The load oriented order release mechanism releases the jobs in the pool to the shop until a certain inventory level at the bottlenecks is reached. Urgent orders are determined according to their calculated release dates. Jobs which have release dates located in a preset time window are called urgent. Two applications of load oriented manufacturing control system were given in the study: BORA-X and KPSF. These systems decreased work in process levels and reduced order lead times.

Hansmann [9] proposed another load oriented order release mechanism. The mechanism first determines the urgent jobs, which have release dates within a previously defined time horizon. Using the database of MRP II, bottleneck machines are identified. Different load limits are determined for bottleneck and non-bottleneck machines by using an optimization procedure. Expected capacity requirements are calculated for each job using a probabilistic statement. As the last step, the jobs whose expected capacity requirements do not exceed the load limits of the work stations are released in the sequence of their release dates. The mechanism was compared with IR. The results showed that it outperforms IR in terms of their combined objective function and mean flowtime in the shop. The combined objective function is the sum of a multiple of mean flow time in the shop and a multiple of mean tardiness.

From the literature review we can make the following observations:

1. ORR mechanisms reduces WIP levels in the shop and the variability of the shop load.

2. ORR mechanisms improve the due date performance of non-due-date oriented heuristics compared to the due date oriented heuristics.

3. The most effective strategy for reducing mean flowtime, mean tardiness and proportion tardy values is to release the jobs immediately.

4. Combination of load smoothing made by the planning system and ORR gives shorter lead times and lower work in process levels.

5. Due date oriented release rules (e.g., FIN, INF) perform better for mean lateness and mean absolute deviation measures.

6. Load oriented release (e.g., AGG, WIBL) rules perform better than due date oriented release rules for mean tardiness and proportion tardy measures.

7. In all the simulation models used for ORR, material handling system and finite buffer capacities are not considered. For that reason these models were not quite capable of modeling the congestion in the system. This can be the reason why researchers have found limited supports for the effectiveness of ORR mechanisms in the literature.

8. The forbidden early shipment is a prevalent characteristic of real systems. But this characteristic has not been included in most of the studies.

In the light of the above observations we reexamine the problem in a dynamic job shop in which early shipments are forbidden. Furthermore our model includes material handling system and finite buffer capacities. This helps us to capture the congestion in the system. Detailed information about our simulation model and propsed study is given in the following chapters.

Chapter 3

Experimental Conditions

In this chapter, we first explain the release mechanisms tested in the experiments. This is followed by system considerations and the simulation model. Finally, we discuss the experimental conditions.

3.1 Release Mechanisms

In this study, we investigate the effects of ORR mechanisms using a simulation model of a dynamic job shop in which early shipments are prohibited. The following eight releasing mechanisms are tested. In each of the following mechanisms, jobs in the pool are ranked according to first in first out (FIFO) rule.

1. Immediate Release (IMR): Jobs are released to the shop as soon as they arrive into the system.

2. Interval Release (IR): Jobs, which arrived, are accumulated for a prespecified time interval. They are released periodically in a batch. In our study, period lengths are chosen as 2 and 8 hours.

3. Aggregate Loading: Two versions of this release mechanism are tested;

(a) Continuous Aggregate Loading (CAGG): Sabuncuoğlu and Hommertzheim [32] used this rule to avoid excessive congestion and traffic on the shop floor. This mechanism attempts to limit the number of jobs in the shop. A newly arrived job is released if the number of jobs in the shop is less than a prespecified value. Else the job waits in the pool. And whenever a job is finished, a job from the pool is released to the shop. In our study, performance of the shop is evaluated for different values of the number of jobs allowed to the shop.

(b) Periodic Aggregate Loading (PAGG): This mechanism was used in the study made by Ragatz and Mabert [31] (The Maximum Number of Jobs (MNJ) mechanism). With this rule, arriving jobs are collected in a pool and the release decision is made at the beginning of each day (by 8 hour intervals). Jobs are released to the shop floor, one at a time, until either all jobs are released or the number of jobs in the shop has reached to a prespecified value. The performance of the shop is also evaluated for different values of the number of jobs allowed into the system.

4. Workcenter Information Based Loading (WIBL): This release mechanism is similar to the one proposed by Melnyk and Ragatz [20] (Workcenter workload trigger, earliest due date selection (WCEDD)).

   This release mechanism uses the workload information of the workstations and information about the jobs in the pool. In our study, workload of a workstation is taken as the sum of the processing times of the jobs waiting at the workstation to be processed plus the sum of processing times of the jobs waiting at the output queues of other workstations to be transported to the workstation and sum of the processing times of the jobs which are, currently, being transported to the workstation. A newly arrived job is released to the shop if the workload of the workstation, at which the first operation of the job will be processed, is less than a presepecified load level. Otherwise the job is placed into the pool. Whenever the total workload of a workstation decreases under a preset load level, a job which has its first operation at the underloaded workstation is selected among the jobs in the pool. Jobs are released until there are no jobs which have their first operations at the underloaded workstation or the total workload of the underloaded workstation increases above the preset load level. Performance of the shop is evaluated for different load levels in our study.

5. Infinite Loading: Two versions of this release mechanism are considered in our study;

    (a) Continuous Infinite Loading (CINF): This mechanism is based on a release date calculation. When a job arrives to the system, release date of the job is calculated using the following equation;

$$R_i = D_i - k_1 * n_i - k_2 * Q_i \tag{3.1}$$

    where,

    R_i = Release time of job i,
    D_i = Due date of job i,
    n_i = number of operations in job i,
    Q_i = the number of jobs on job i's routing,
    k_1, k_2 = planning factors.

    Above equation was also used for release date calculation by Ragatz and Mabert [31] (Modified Infinite Loading (MIL)). In our study, Q_i includes the jobs in input queues at machines on job i's routing, the jobs in output queues of other machines waiting to be transported to a machine on job i's routing and the jobs which are currently being transported to a machine on job i's routing.

    If the release date calculated is before the current time, the job is released, immediately, to the shop. Else the job waits in the pool until its release date.

    Mahmoodi et al. [18] tested a similar release mechanism with a different equation for release date calculation.

(b) Periodic Infinite Loading (PINF): This release mechanism uses the equation 3.1 for calculating the release date. This is called as Modified Infinite Loading by Ragatz and Mabert [31]. Jobs which arrive into the system, are directly placed into the pool. Release decision is made at the beginning of 8 hour periods. If the release date of the job is before the current time or before the beginning of the next 8 hour period, the job is released immediately. Otherwise, the job is returned to the pool and its release date is recalculated at the beginning of the next 8 hour period.

Bobrowski and Park [5] tested a similar release mechanism with a different equation for release date calculation.

6. Forward Finite Loading (FFIN): This release mechanism was proposed by Bobrowski and Park [5]. Detailed information about the job and the shop is used in this mechanism. A current-workload profile for each workstation in the shop is maintained by employing a planning horizon that is broken into time buckets (loading periods). The workload profile indicates the amount of work released for the workcenter for each time bucket in the planning horizon.

   This mechanism loads the operations of the job into available capacity for the appropriate workstation by starting from the first operation. If there is no adequate capacity at the time bucket considered, then next time bucket in the planning horizon is evaluated for loading the operation.

   Flow time of a job is forecasted by using the processing time of each operation;

$$\text{flowtime} = k * \text{processing time} \tag{3.2}$$

   where,
   k=planning factor, $(k \geq 1)$.

   Completion time of the job is estimated by the load period of the last operation. The job is released to the shop if due date of the job is less than the last operation load period. Otherwise, the job is returned to the pool and the release decision about the job is made at the beginning of the next 8 hour interval which is the length of a loading period.

For keeping the load profile of each workstation upto date, we update the profile whenever an operation of a job is finished. We delete the processing time of the finished operation from the corresponding time bucket in the load profile. Then following operations of the same job are reloaded by using equation 3.2.

3.2 System Considerations and Simulation Model

A hypothetical factory was used in our simulation study. The model was written in the SIMAN simulation language [27][35]. We also wrote some parts of the code in the C language [16] to implement the release mechanisms. C subroutines were linked with SIMAN in UNIX environment.

The assumptions, which are generally done in classic job shop scheduling studies, are given in [2]. We made the following assumptions in our study:

1. Jobs consist of strictly ordered operation sequences.
2. A given operation can be performed by only one type of machine.
3. There is only one machine of each type in the shop.
4. Processing times as well as due dates are known at the time of arrival.
5. There are no setup times.
6. Once an operation is begun on a machine, it cannot be interrupted.
7. An operation may not begin until its predecessors are completed.
8. Each machine can process only one operation at a time.
9. Each machine is continuously available for production.

Table 3.1: Vehicle travel distance between stations in the layout,distance units

Station No.	1	2	3	4	5	6	7	8
1	0	80	85	75	130	95	40	125
2		0	35	95	80	145	70	135
3			0	60	45	110	105	100
4				0	55	50	115	80
5					0	85	150	55
6						0	135	30
7							0	165
8								0

Layout of the factory is given in Figure 3.1. The layout is bi-directional. Distances between the workstations is in Table 3.1. Some characteristics of the simulation model are identical to those used by Melnyk and Ragatz [20]. The model has the following characteristics;

Number of workstations	6
Order routings	Random, no return visit to a workstation.
Operations per job	Uniform[1,6]
Interarrival distribution	Exponential
Service time distribution	Erlang(mean=1.0 h)

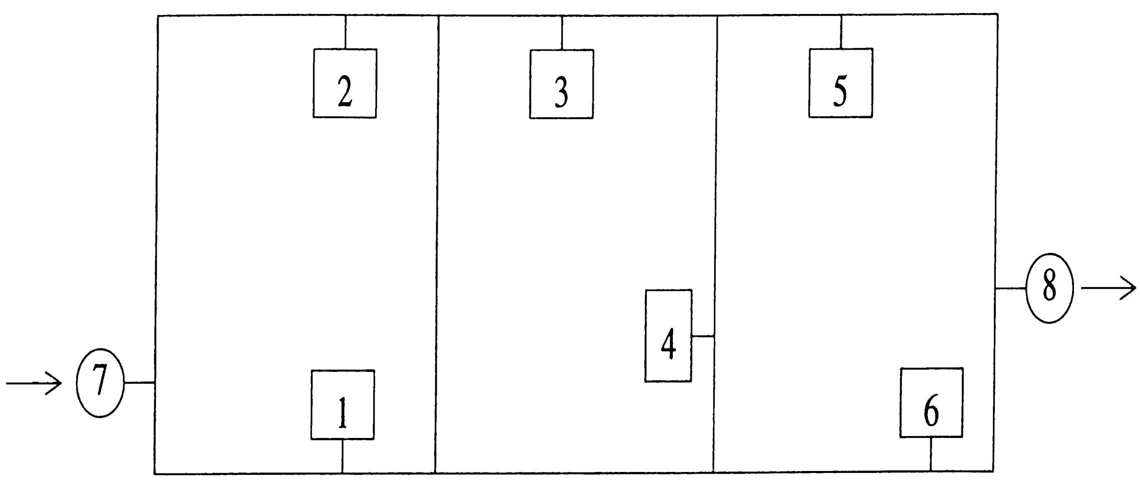

Figure 3.1: Layout of the Shop

When a job arrives, a due date is assigned for the job. Formula used to calculate the due date is the same as the one which Melnyk and Ragatz [20] used;

$$D_i = AT_i + k * TWK_i \tag{3.3}$$

where,

D_i = Due date of job i,

AT_i = Arrival time of job i,

TWK_i = Total operation time for job i,

k = A constant which determines due date tightness.

Evaluation of various due date assignment rules is given in [30] by Ragatz and Mabert.

Tsubone et al. [37] presented interactive due date management system for job shops. This system allows the user to accept or reject the job which is negotiated and to adjust the production capacity. They applied the system to a real production environment. The system decreased the variance in the flowtime and the number of jobs which missed their due dates. It provided a quick and accurate estimate of the flowtime for the job.

In our simulation model, we assumed that early shipment of completed jobs is forbidden. Kanet and Christy [15] simulated a job shop with the same assumption and compared two lead time estimation rules. They showed that TWK method is the best and provides lower mean tardiness and lower mean inventory values.

Every workstation involves one machine in our simulation model. We assumed that each machine has one input and one output queue which has finite capacities. After some pilot simulation runs, we set input queue capacity to three and output queue capacity to one. Every workstation has also one buffer area with infinite capacity, representing a common deparmental storage area.

Described structure of the workstations helps us for modeling the congestion and for preventing deadlocks in the shop. Deadlock is a complete seizure of the job flow throughout the shop. Problem of deadlocking occurs during the operation of flexible manufacturing systems. Wysk et al. [40] presents some approaches to resolve deadlock problems in FMS.

In our simulation model, transportation of the jobs between workstations is achieved by unit load transporters. The model includes five transporters with a speed of 250 distance units per hour.

Usage of finite capacity queues and material handling system forms the difference of our simulation model from the models used in the order release literature. Forbidden early shipment is not also considered in most of the past research.

For operating a material handling system, two dispatching decisions should be made:

1. Decision for selecting a transporter from a set of idle transporters to assign for a request.

2. Decision for selecting a workstation from a set of workstations which are, simultaneously, requesting for a transporter.

The first class of problems is called workstation initiated task assignment problems and the second class of problems is called vehicle initiated task assignment problems [7]. Egbelu and Tanchoco [7] presents some methods for the above task assignment decisions. They investigated the effects of these methods on job shop performance.

For the workstation initiated task assignment we used Smallest Distance to Station (SDS) rule. In this rule, the transporter, which is nearest to the station, from where the request is made, is allocated.

For the vehicle initiated task assignment we used modified-first-come-first-served (MOD FCFS) rule which was used by Srinivasan and Bozer [34]. In this rule, the transporter checks the output queue of the destination station after delivering its load. If there are unassigned loads in the output queue, it picks up the oldest unassigned load in that queue. If there is no unassigned load in the output queue, the transporter is directed to the oldest unassigned move request in the system. If there is no unassigned move request in the system, the transporter stays idle at the station where it delivered its load.

Because of the structure of the workstation modelled is different than the previous ones in the literature, as we noted above, we made some extensions to the operational rules we described above. Operational rules were implemented as follows: A transporter request is made whenever a job is released to the shop from the pool or whenever a job is put in the output queue.

When a transporter receives to its destination station, it unloads its load to the input queue if there is empty place in the input queue and there is no job waiting at the buffer. Otherwise, it unloads its load to the buffer. We assumed that the distance between the machine and the buffer is 25 distance units and constant for each workstation.

After unloading the job to the input queue, the transporter picks up the oldest unassigned load at the output queue. If there is no unassigned load at the output queue, the transporter is directed to the station from where the oldest transporter request has been made. If there is no transporter request in the system, the transporter stays idle at the station.

If the operation was finished and there is no place at the output queue, the job waits on the machine until one job at the output queue is removed.

If the number of jobs in the input queue decreases to one, and if there are some jobs waiting in the buffer, a transporter request is made by the station. The transporter, which answers the request, fills the input queue by the jobs in the buffer by transporting the jobs one by one. Then, it picks up the oldest unassigned load at the output queue. If there is no unassigned load at the output queue, the transporter travels to the station from where the oldest request was made. If there is no transporter request, it stays idle at the current station.

If the transporter unloads its load to the buffer and there is no place in the input queue, the transporter checks the output queue for an unassigned job. If there are unassigned jobs, it picks up the oldest one. Otherwise it answers the oldest unassigned transporter request in the system. If there is no transporter request in the system, the transporter stays idle at the station.

If the transporter unloads its load to the buffer and there is some place in the input queue and if there is no transporter which has been allocated to fill the input queue, the transporter fills the input queue by tansporting the jobs in the buffer, one by one. After filling the input queue, the transporter picks up the oldest unassigned load at the output queue. If there is no unassigned load at the output queue, the transporter is directed to the station from where the oldest transporter request has been made. If there is no transporter request in the system, the transporter stays idle at the station. If there is a transporter which has been allocated to fill the input queue, the transporter does not transport any of the job in the buffer. It picks up the oldest unassigned load at the output queue. If there is no unassigned load at the output queue, the transporter is directed to the station from where the oldest transporter request has been made. If there is no transporter request in the system, the transporter stays idle at the station.

3.3 Experimental Design

There are four factors considered in the experiments:

1. Release mechanism
2. Dispatching rule
3. Machine and transporter utilization
4. Due date tightness

Eight different release mechanisms are tested in our study;

- Immediate release (IMR)

- Interval release (IR)
- Continuous aggregate loading (CAGG)
- Periodic aggregate loading (PAGG)
- Workcenter information based loading (WIBL)
- Continuous infinite loading (CINF)
- Periodic infinite loading (PINF)
- Forward finite loading (FFIN)

Two dispatching rules are used in the experiments:

- SPT
- MOD

SPT (Shortest Processing Time): Priority is given to the job with the smaller processing time.
MOD (Modified Operation Due Date): Priority is given to the job with the smaller value of modified operation due date, d'_{ij}. Modified due date of an operation is the maximum of its original operation due date and its earliest operation finish time. Priorities of the jobs are determined whenever we unload the machine. Modified due date of an operation is calculated as follows;

$d'_{ij} = max(d_{ij}, \text{current time} + p_{ij})$
where,

$$\begin{aligned} d_{ij} &= (\text{processing time up to operation } j) * r, \\ r &= (\text{due date} - \text{release time})/\text{total processing time}, \\ p_{ij} &= \text{processing time of operation } j \text{ of job } i. \end{aligned}$$

Two levels are set for machine and transporter utilizations:

- High machine and high transporter utilization

- Low machine and low transporter utilization

For high machine and high transporter utilization case, machine utilization is set to 91% and transporter utilization is set to 93% utilization levels. It is achieved by using 0.705 hours mean interarrival time, 5 transporters with velocities 250 distance units per hour and first in first out (FIFO) dispatching rule.
For low machine and low transporter utilization case, machine utilization is set to 66% and transporter utilization is set to 63%. This is achieved by changing the mean interarrival time to 0.9 hours.

Two levels of due date tightness are studied throughout the study:

- Tight
- Loose

The value of k in the equation 3.3, determines the tightness of the due dates. We set the value of k such that; 10 percent of the jobs become tardy in loose case and 30 percent of the jobs become tardy in tight case if we use first in first out (FIFO) dispatching rule. Values of k are given below:

Machine and transporter utilization	Due date tightness	k
Low	Loose	6.5
Low	Tight	4.1
High	Loose	33.0
High	Tight	15.0

We use the method of batch means [17] for output data collection. We make a long simulation run and break down the run into some small subruns (batches). In our study, the warmup period is set to be 2500 job completions. One simulation run consists of twenty batches. Each batch is finished when 1000 jobs are completed. So 22500 jobs are completed during a simulation run.

We use a full factorial design [17]. We take simulation runs for each possible combination of the levels of the factors. A factorial design is necessary when interaction might be present among the factors.

Common random numbers method [17] is used as a variance-reduction technique in this study. This method aims to compare different order release mechanisms under similar experimental conditions. This is achieved by using common random numbers in different experiments.

Simulation results of Immediate Release (IMR) are given in Table A.1 in Appendix. As shown in this Table, the following performance measures are used to collect the relevant statistics:

$$
\begin{aligned}
\text{Flowtime} &= \text{time in pool} + \text{time in shop} \\
\text{Time in system} &= \text{time in pool} + \text{time in shop} + \\
&\quad\ \text{time in finished goods inventory} \\
\text{Tardiness} &= max(0, C_i - D_i)
\end{aligned}
$$

$$
\begin{aligned}
\text{Lateness} &= C_i - D_i \\
\text{Absolute deviation} &= \mid C_i - D_i \mid
\end{aligned}
$$

where, C_i and D_i are completion time and due date of job i, respectively. In the next paragraph we describe additional statistics collected in this study.

Percent tardy measure is used to measure the percent of jobs finished after their due dates among all finished jobs. Material handling (M/H) time gives the duration of time during which the job is carried by a transporter. Time in output queue (OQ) is the time a job spends in the capacitated output queues or in the buffers. Blocking time gives the length of the time during which the job is waited on the machines due to the blocking situation. Blockage occurs if the output queue is full when the machine finishes its operation.

In addition to the the measures described above, time in input queue (IQ), mean number of jobs in the shop, standard deviation of flowtime, and standard deviation of number of jobs in the shop measures are collected. The results are also reported for these statistics.

In the next chapter, we present experimental results and computational analysis. Statistical tests are also included to justify our conclusions.

Chapter 4

Experimental Results

In this chapter we evaluate the release mechanisms. These methods will be tested under various experimental conditions for different performance measures. We also present statistical tests to justify our conclusions.

In previous studies, it was observed that the level of WIP can be reduced by the effective use of ORR mechanisms. This is because the congestions on the shop floor is reduced by controlling the input rate. At the same time there is a dilemma that reduction in congestion in the system does not lead to reduction in overall flowtimes in the system. Indeed, as reported in the literature, ORR mechanisms other than IMR deteriorate flowtimes.

To approve or disprove this stated observation, we used the continuous aggregate loading mechanism (CAGG) and tested its performance in various shop structures. In these experiments, the SPT dispatching rule was used. Machine and transporter utilizations were set to high and due date tightness was set to loose. The following jobs shop structures (or cases) were studied:

1. The shop which does not include material handling system and capacitated queues (i.e., a traditional job shop).

2. The shop in which there is a material handling system, but not capacitated queues.

3. The shop considers capacitated queues, but not a material handling system.

Detailed simulation results of the continuous aggregate loading mechanism are presented for these shop structures in Tables A.12-A.14 in Appendix. The results of immediate release (IMR) are also given in Table A.1. Here IMR is used as a benchmark in comparisons.

Figure 4.1 shows mean flowtime performances of these three systems at varying values of number of jobs allowed into the system, which is the parameter of the continuous aggregate loading release mechanism.

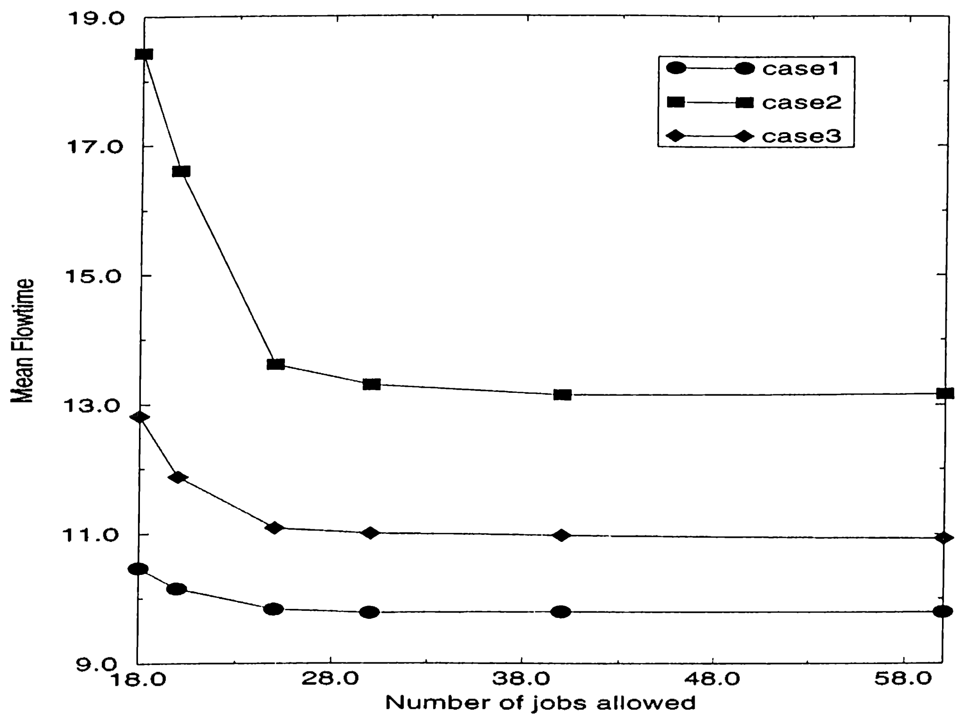

Figure 4.1: Mean Flowtime versus number of jobs allowed for the three cases (Aggregate Loading (cont.) with SPT dispatching rule under high machine, transporter utilization, and loose due dates.)

As shown in the Figure 4.1, limiting the number of jobs in the shop increases the mean flowtime value for each of the three system structures tested. The results also indicated that consideration of a material handling system increases mean flowtime values and the curve shifts upward. We also noted that flowtime values found in the third case lie between the first and the second case. This means that adverse effect of MHS on the system performance has more than the capacitated queues. From these results it seems obvious that limiting the jobs in the shop causes an increase in the waiting times of the jobs in the pool which in turn results in an increase in mean flowtime values. Note also that Case 1 is the traditional job shop considered in the ORR literature. Hence, our result simply verify the previous studies that controlling input does not necessarily reduce overall lead times.

4.1 Continuous Aggregate Loading

We also tested continuous aggregate loading for a shop in which both capacitated queues and material handling system are considered simultaneously. The results of simulation experiments are presented in Tables A.4-A.11 in Appendix. For high utilization case, we tried 10 different number of jobs allowed into the shop values. These are 25, 30, 35, 40, 50, 60, 70, 80, 90, 120. And for low utilization case, 7 different values were tried. These are 12, 14, 16, 18, 20, 25, 30.

Figures 4.2 and 4.3 depict mean flowtime performances in terms of the number of jobs allowed into the system for SPT and MOD dispatching rules, respectively. Again in these experiments loose due dates and high machine and transporter utilizations were used. As compared to the previous three cases discussed, we obtained U-shaped behaviour at this time. As can be seen in Figure 4.2 the mean flowtime increases as we allow a small number of jobs into the shop. Because the jobs spend their time in the pool. In otherwords, mean flowtime decreases as we allow more jobs in the system. After some point, however, it again starts increasing due to the congestion on the shop floor. This shows clearly the benefit of input regulation which was not previously observed in the ORR literature. Only few researchers have made similar observations in some other problem contexts (Sabuncuoğlu and

Hommertzheim [32], Taghaboni-Dutta and Tanchoco [36]).

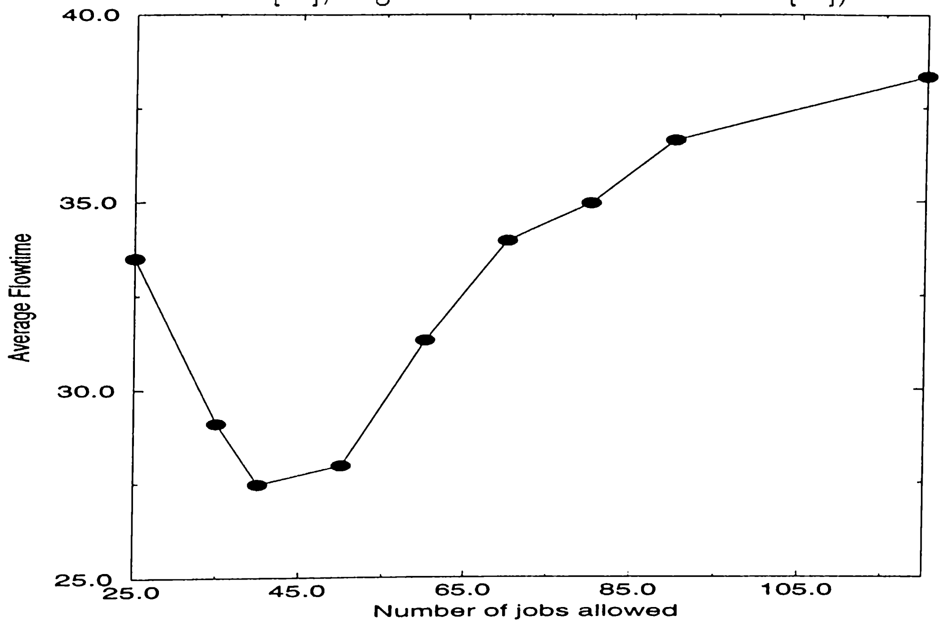

Figure 4.2: Mean Flowtime versus number of jobs allowed (For Aggregate Loading (cont.) with SPT dispatching rule under high machine, transporter utilization, and loose due dates)

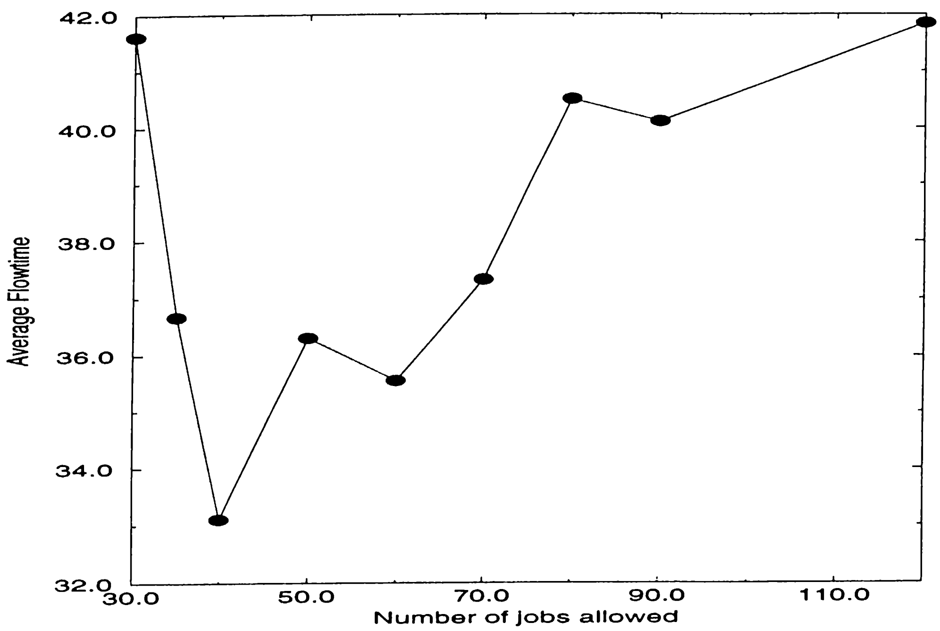

Figure 4.3: Mean Flowtime versus number of jobs allowed (For Aggregate Loading (cont.) with MOD dispatching rule under high machine, transporter utilization, and loose due dates)

Due date tightness= loose , Dispatching rule= SPT					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
17.046	23.911	5.347	3.19	0.0047	(5.85,28.24)

Due date tightness= tight , Dispatching rule= SPT					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
12.497	18.706	4.183	2.99	0.0076	(3.74,21.25)

Due date tightness= loose , Dispatching rule= MOD					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
11.049	16.502	3.69	2.99	0.0075	(3.32,18.77)

Due date tightness= tight , Dispatching rule= MOD					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
15.444	21.070	4.711	3.28	0.0040	(5.58,25.31)

Table 4.1: Paired t-test results for IMR and CAGG. Machine and transporter utilizations are high.

Significance of differences between the immediate release and the continuous aggregate loading mechanism was also investigated. We used t-test [12] to compare the immediate release with the best performer of the continuous aggregate loading (i.e., the continuous aggregate loading with a parameter that gives the smallest mean flowtime). As shown in Table 4.1, the results indicated significant differences between the policies in all experimental conditions.

We also analyzed the components of the flowtime to get better understanding of the system behaviour as a function of varying values of number of jobs allowed. The results are displayed in Figures 4.4 and 4.5 for SPT and MOD dispatching rules. Again, simulation runs were taken at the standard experimental condition (i.e., loose due dates and high utilization rates). What happens is as follows: if we increase the number of jobs allowed, the waiting time of jobs in the pool decreases. Material handling time also increases because the transporters often visit the buffers (see Tables A.4 and A.6). There is a slight increase at time in input queue. Blocking time of a job increases because the machines are blocked more often in that case. Furthermore, time in output queue increases since the transporters become busy most of the time when there are more number of jobs on the shop floor.

In order to measure sensitivity of the results to the system load level, we repeated our experiments under low machine and MHS utilization rates. Figures 4.6 and 4.7 depict mean flowtimes at varying values of the number of jobs allowed for SPT and MOD dispatching rules. The results showed that when the utilization is low, limiting the number of jobs in the shop does not improve the flowtime. In otherwords, the potential benefits of ORR (or input regulation) are not realized when the system is lightly loaded. It seems the input control is only beneficial when the system is highly loaded (i.e., high congestion on the shop floor).

The simulation results for other performance measures can be summarized as follows: When the number of jobs allowed in the shop is increased; level of WIP and standard deviation of WIP increases. The time in the pool decreases and the time in the shop increases. Percent tardy, mean tardiness, mean lateness and time in system displayed more or less the same behaviour of the mean flowtime. (Figure 4.8 shows the change of mean tardiness and Figure 4.9 shows the change of percentage of tardy jobs by the number of jobs allowed for SPT dispatching rule under high machine and transporter utilization and loose due dates.

For the low utilization case (see Tables A.8-A.11): mean absolute devation is minimized by allowing a large number of jobs into the shop for tight due dates and small number of jobs for loose due dates. Time in the system is reduced and the time in FGI is increased by allowing more jobs into the shop.

For the high utilization case (see Tables A.4-A.7). allowing too many and too few jobs in the shop deteriorates mean absolute deviation for tight due dates. And it is better to allow few or many jobs in the shop for mean absolute deviation measure under loose due dates. Moreover. allowing more jobs into the shop increases the standard deviation of mean flowtime.

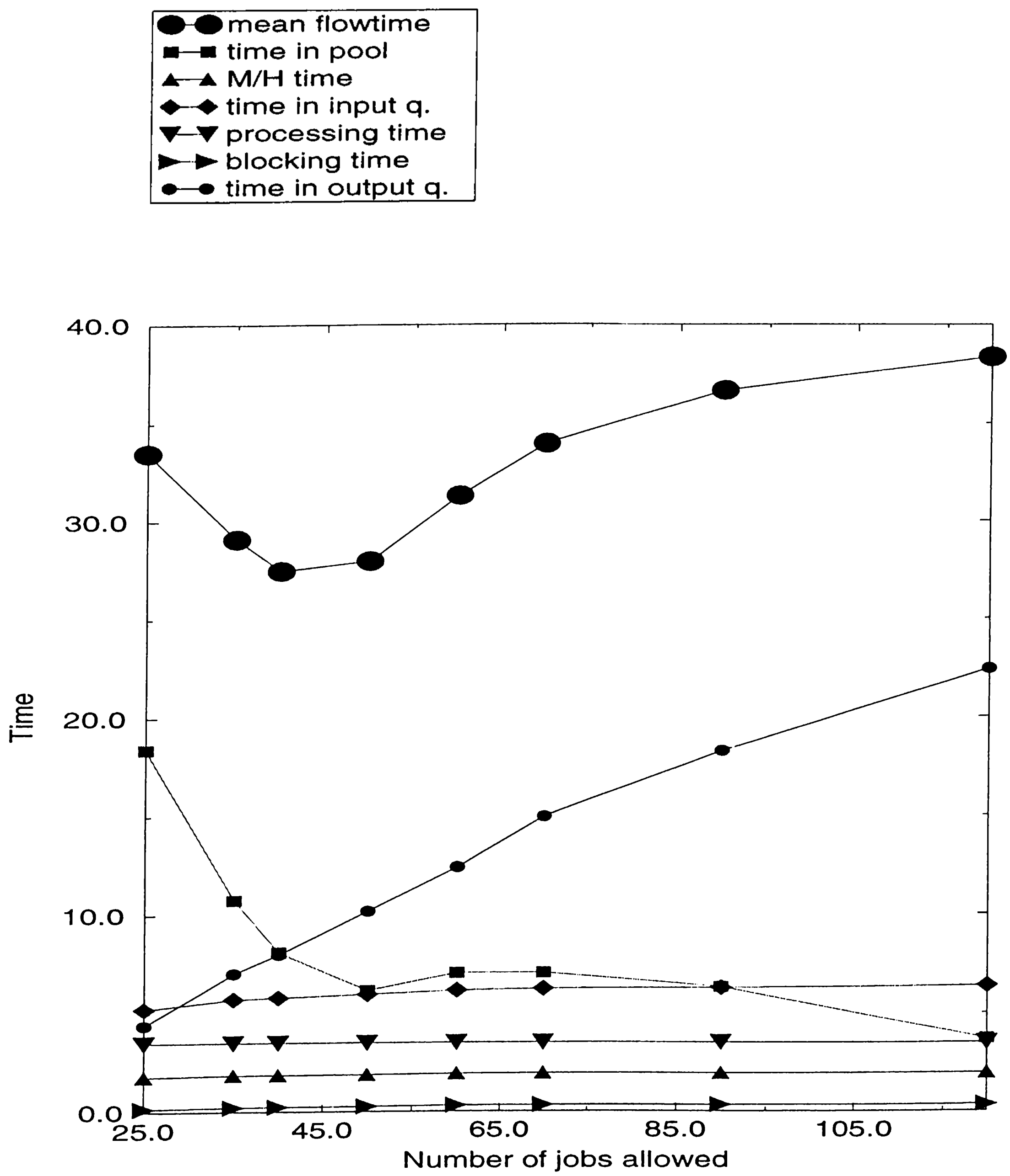

Figure 4.4: Components of the flowtime (For Aggregate Loading (cont.) with SPT dispatching rule under high machine, transporter utilization, and loose due dates)

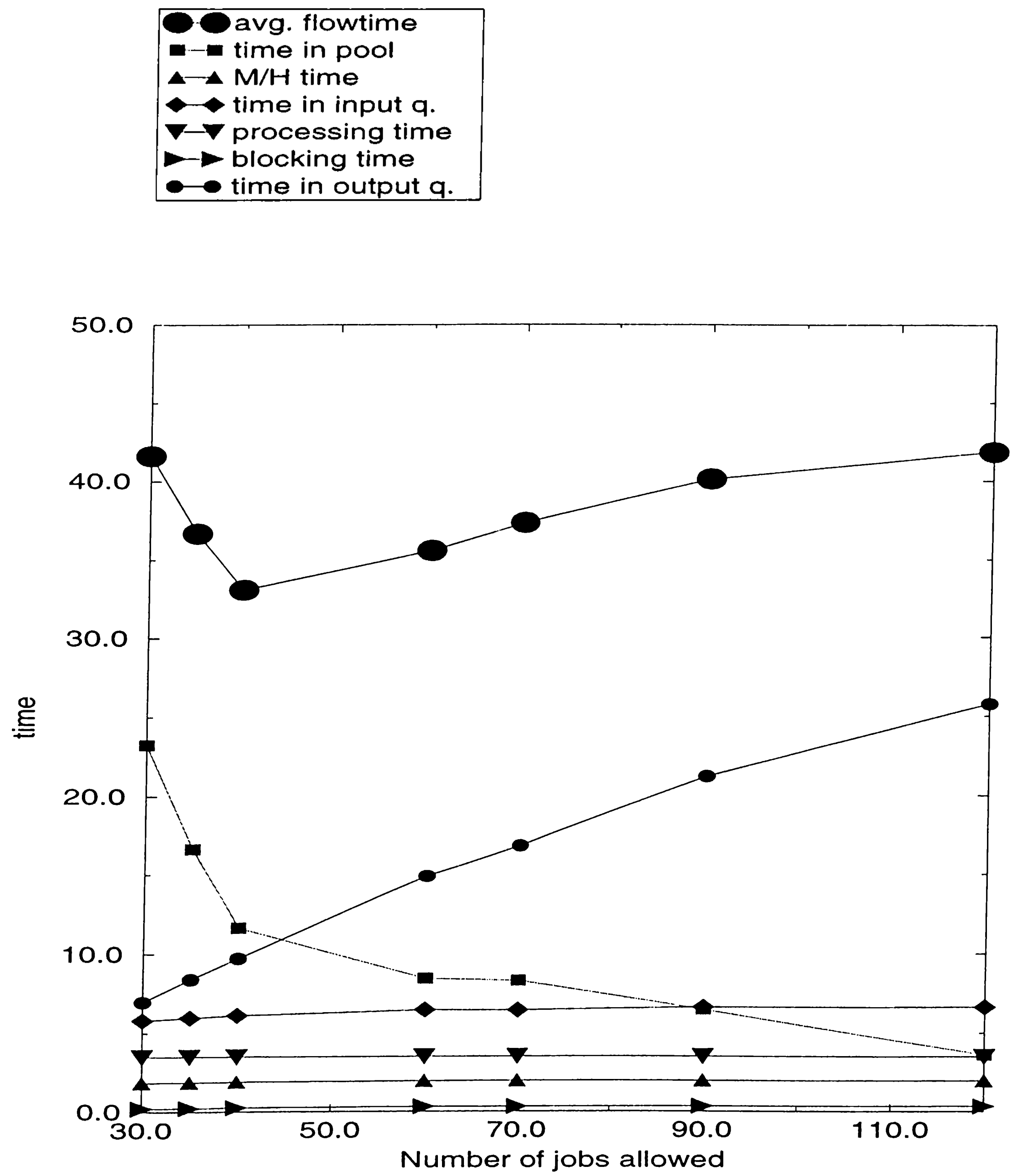

Figure 4.5: Components of the flowtime (For Aggregate Loading (cont.) with MOD dispatching rule under high machine, transporter utilization, and loose due dates)

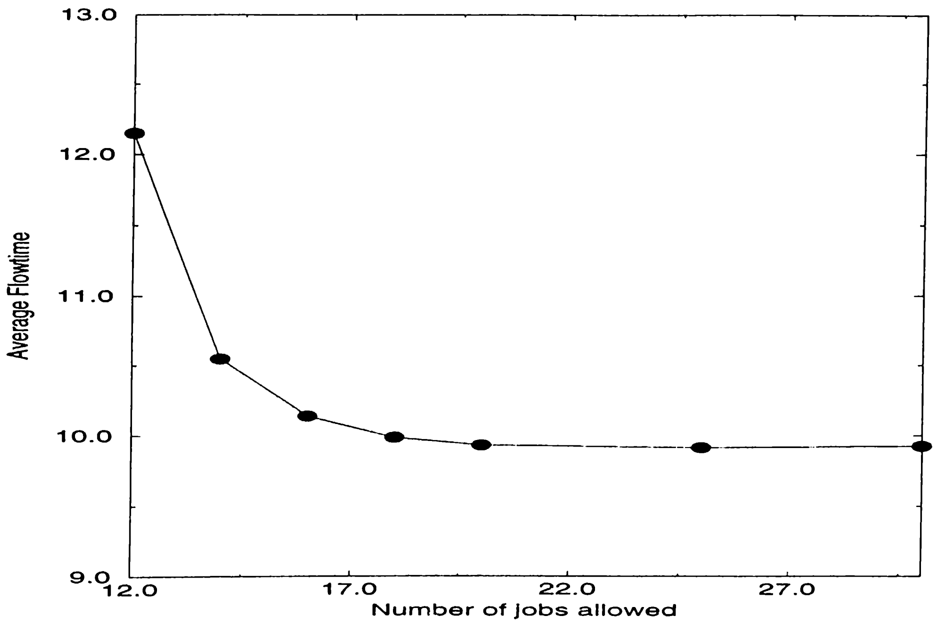

Figure 4.6: Mean Flowtime versus number of jobs allowed (For Aggregate Loading (cont.) with SPT dispatching rule under low machine, transporter utilization, and loose due dates)

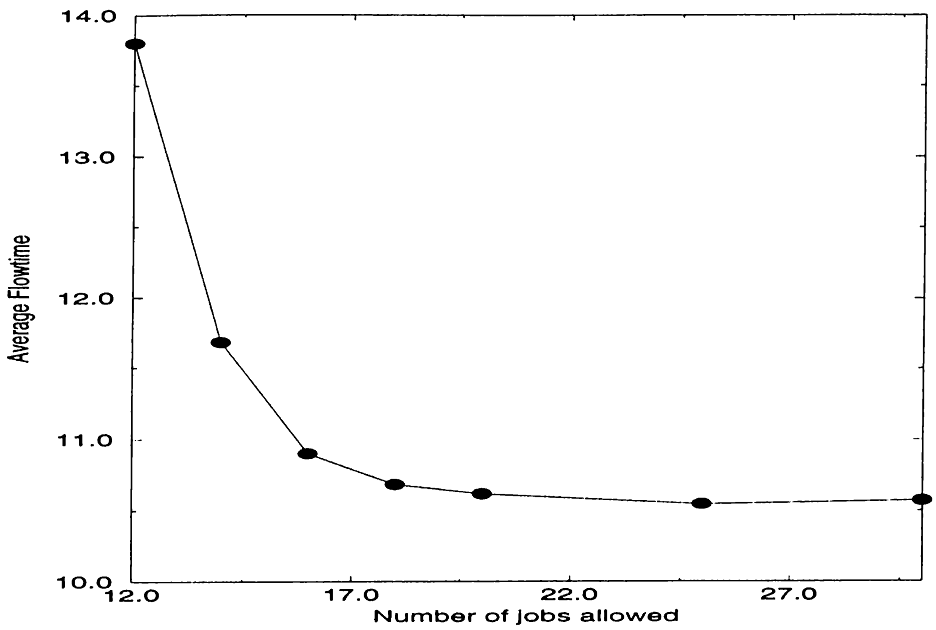

Figure 4.7: Mean Flowtime versus number of jobs allowed (For Aggregate Loading (cont.) with MOD dispatching rule under low machine, transporter utilization, and loose due dates)

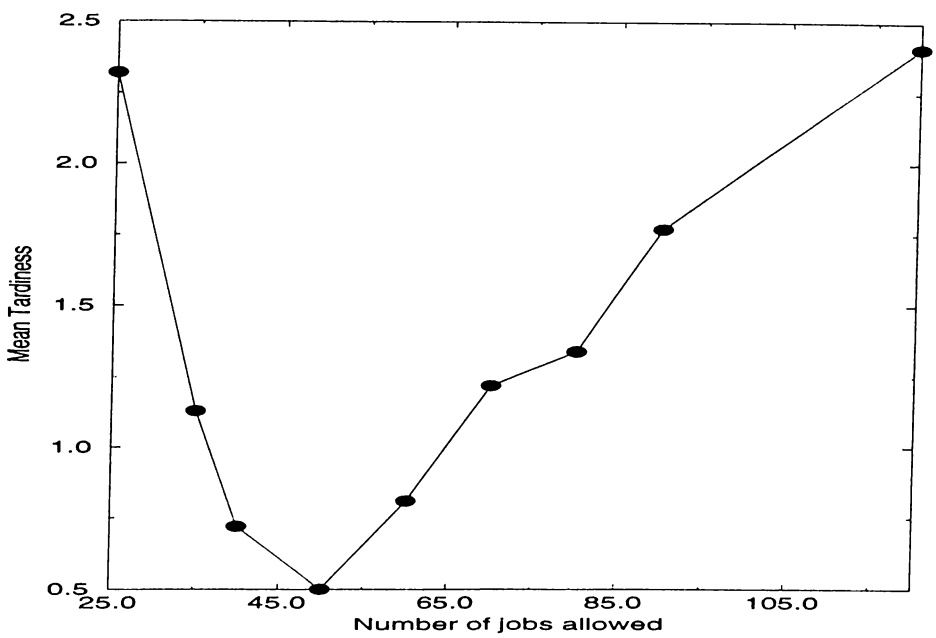

Figure 4.8: Mean Tardiness versus number of jobs allowed (For Aggregate Loading (cont.) with SPT dispatching rule under high machine, transporter utilization, and loose due dates)

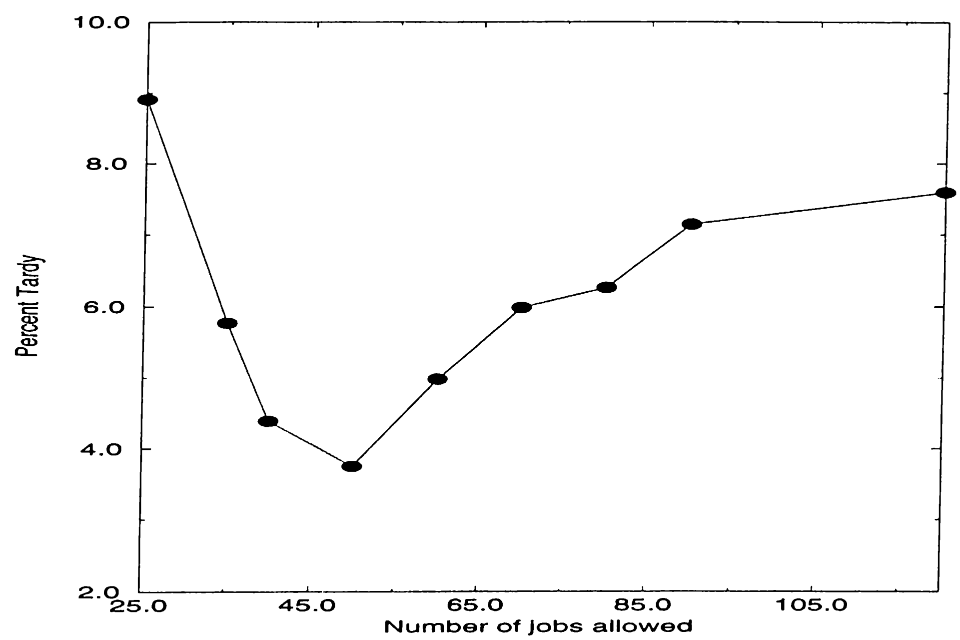

Figure 4.9: Percent Tardy versus number of jobs allowed (For Aggregate Loading (cont.) with SPT dispatching rule under high machine, transporter utilization, and loose due dates)

4.2 Interval Release

After the continuous aggregate loading, we tested the interval release. This release mechanism is probably the most used ORR policy in practice. Simulation results are given in Table A.2 and A.3 in Appendix.

Figures 4.10-4.13 also show mean flowtimes for varying values of the interval length under loose due date tightness. The similar behaviours were observed for tight due date cases. These figures show that the use of small interval lenghts improves mean flowtime measure.

In general, as the interval length increases from 2 to 8 hours, mean flowtime, mean tardiness, percent tardy, mean lateness, time in system, time in shop and time in pool values increase. The bigger values of the interval length also deteriorates the performance measures such as, the number of jobs in the shop, standard deviation of the number of jobs in the shop, and standard deviation of flowtime. So, it is better to use immediate release instead of interval release to improve these performance measures.

However, the absolute deviation measure is improved by the increase in interval length for loose due dates, even though it increases for the tight due date case. The use of 8.0 hours interval length rather than 2.0 hours decreases the time in finished goods inventory for every utilization level. Our results are similar to the ones obtained by Panwalkar, Smith and Dudek [25]. They also found that it is better to use small interval lengths.

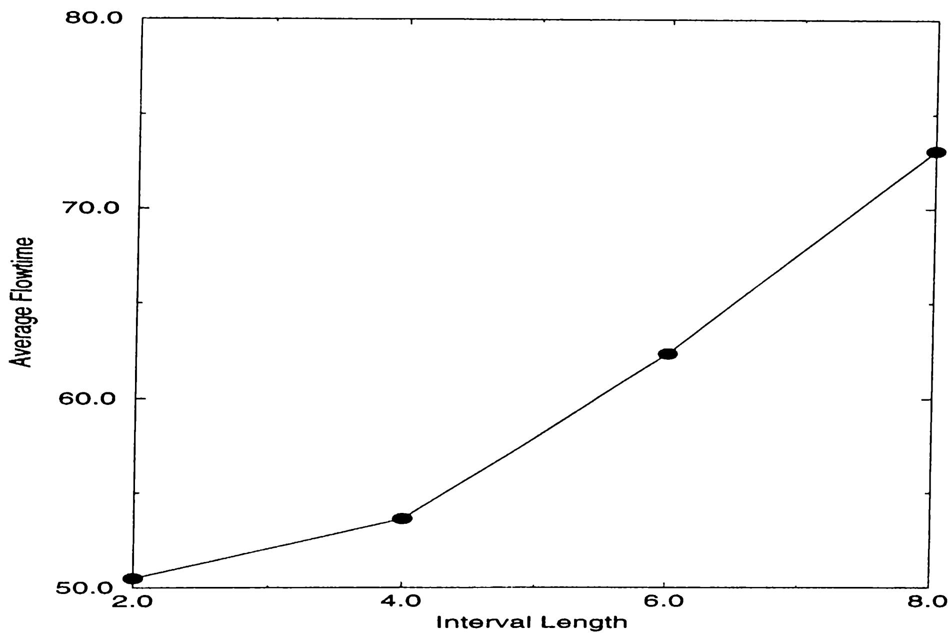

Figure 4.10: Mean Flowtime versus Interval Length (For Interval Release with SPT dispatching rule under high machine, transporter utilization, and loose due dates)

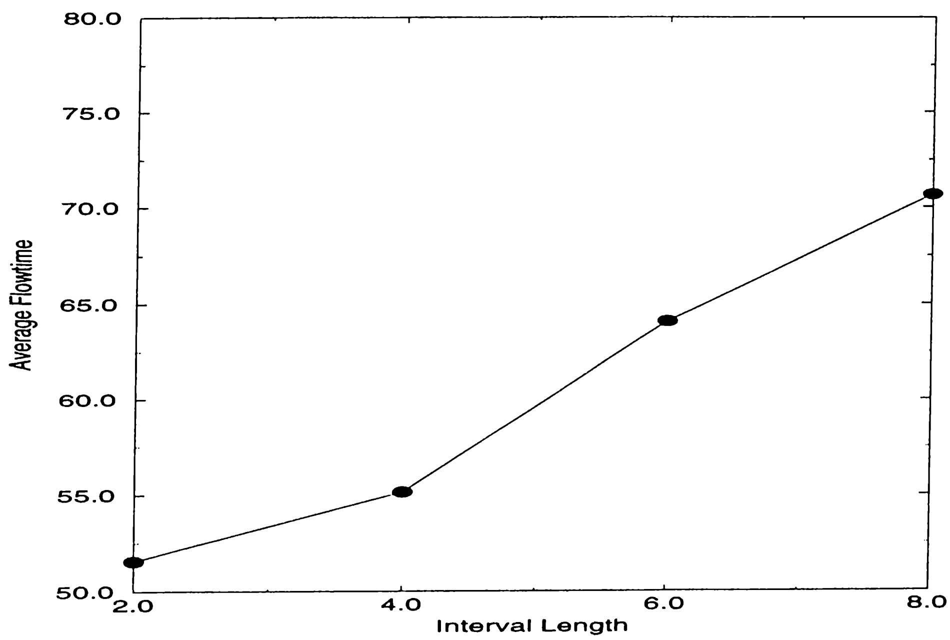

Figure 4.11: Mean Flowtime versus Interval Length (For Interval Release with MOD dispatching rule under high machine, transporter utilization, and loose due dates)

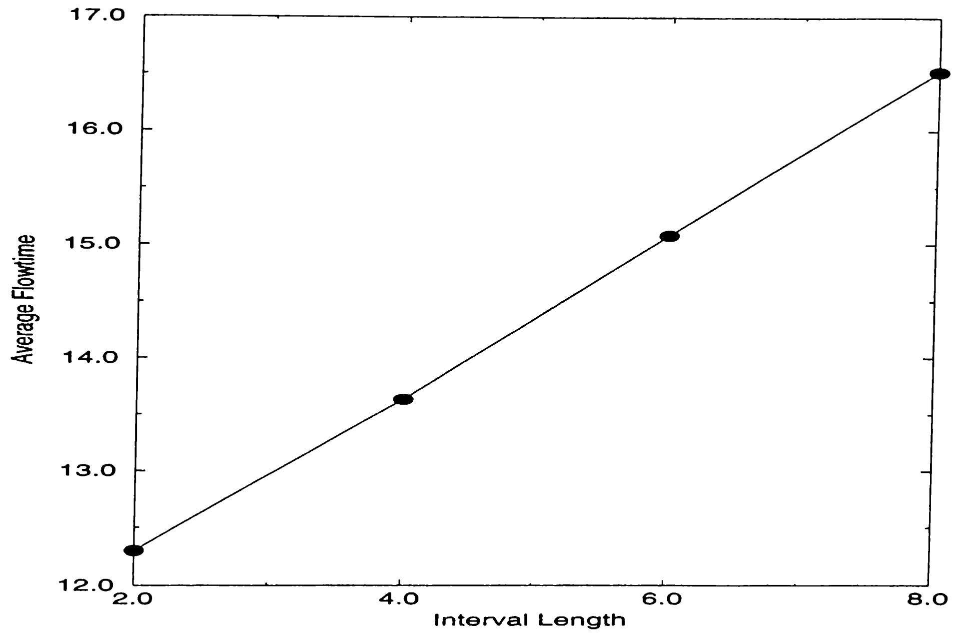

Figure 4.12: Mean Flowtime versus Interval Length (For Interval Release with SPT dispatching rule under low machine, transporter utilization, and loose due dates)

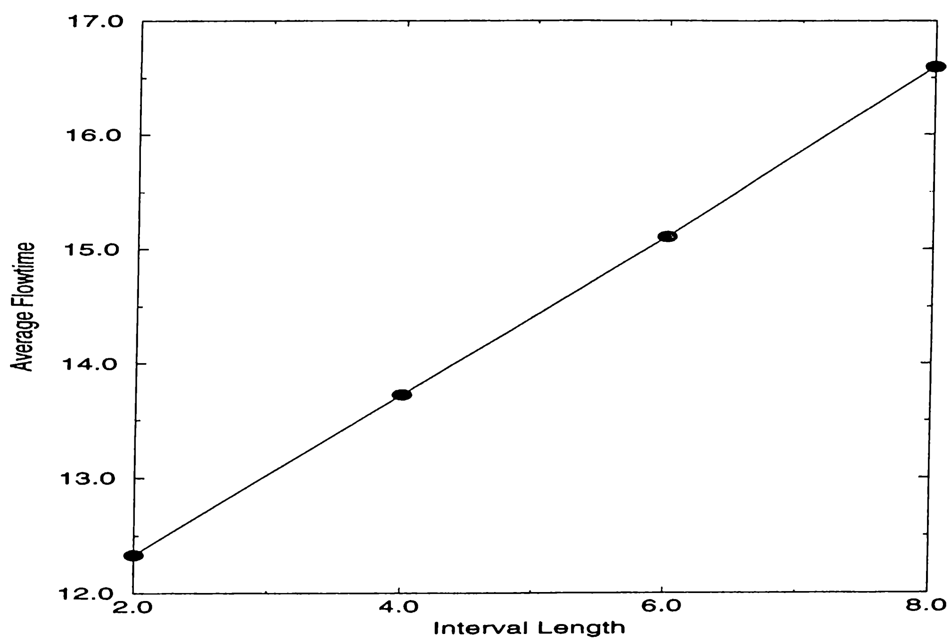

Figure 4.13: Mean Flowtime versus Interval Length (For Interval Release with MOD dispatching rule under low machine, transporter utilization, and loose due dates)

4.3 Periodic Aggregate Loading

A periodic version of aggregate loading has been also studied in this research. As described in the previous section, jobs are placed into a pool and released at the beginning of each period one at a time until the system load reaches a predetermined level.

For high utilization case, we tried 8 different number of jobs allowed into the shop values. These are 50, 60, 70, 80, 90, 100, 120, 150. And for low utilization case, 5 different values were tried. These are 20, 22, 25, 30, 35.

Figures 4.14-4.17 show the mean flowtime as a function of the number of jobs allowed for periodic aggregate loading under loose due dates. Details of the results can be found in Tables A.15-A.22 in Appendix. Again the experiments are repeated for varying values of the load parameter for each condition. As shown in Figures 4.14 and 4.15, the flowtime plot resembles U-shaped curve for high utilization case. Note that U shape of the curve is not very clear compared to the continous aggregate loading case because of randomness in the observations. As can be noticed, the minimum mean flowtime achieved by this case is smaller than the mean flowtime value found for interval release for high utilization. Difference between the mean flowtime value found by interval release and the minimum flowtime value found by the periodic aggregate loading is found significant for high utilization case as shown in Table 4.2. For low utilization case, limiting the number of jobs in the shop does not improve the mean flowtime measure.

Similar observations were made for mean tardiness, percent tardy, mean lateness and time in sytem measures. It was also observed that limiting the number of jobs in the shop deteriorated the mean absolute deviation performance for low utilization case. For high utilization case, the mean absolute deviation was improved by limiting the number of jobs in the shop. In general, increasing the number of jobs allowed reduced the time in pool and increases the time in the shop values. Whereas reducing the value of load parameter (i.e., the number of jobs allowed into the shop) improved mean WIP in the

Due date tightness= loose , Dispatching rule= SPT					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
12.875	12.612	2.820	4.57	0.00	(6.97,18.78)
Due date tightness= tight , Dispatching rule= SPT					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
17.487	16.56	3.703	4.71	0.00	(9.69,25.19)
Due date tightness= loose , Dispatching rule= MOD					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
10.785	8.976	2.007	5.37	0.00	(6.58,14.99)
Due date tightness= tight , Dispatching rule= MOD					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
15.737	16.92	3.783	4.16	0.0005	(7.82,23.66)

Table 4.2: Paired t-test results for IR and PAGG. Machine and transporter utilizations are high.

shop and standard deviation of WIP performances. While the standard deviation of flowtime was improved for small values of the number of jobs allowed under high utilization, we did not observe a significant difference between standard deviation of flowtime values under low utilization. We observed that time in FGI (finished goods inventory) is small for larger mean flowtimes.

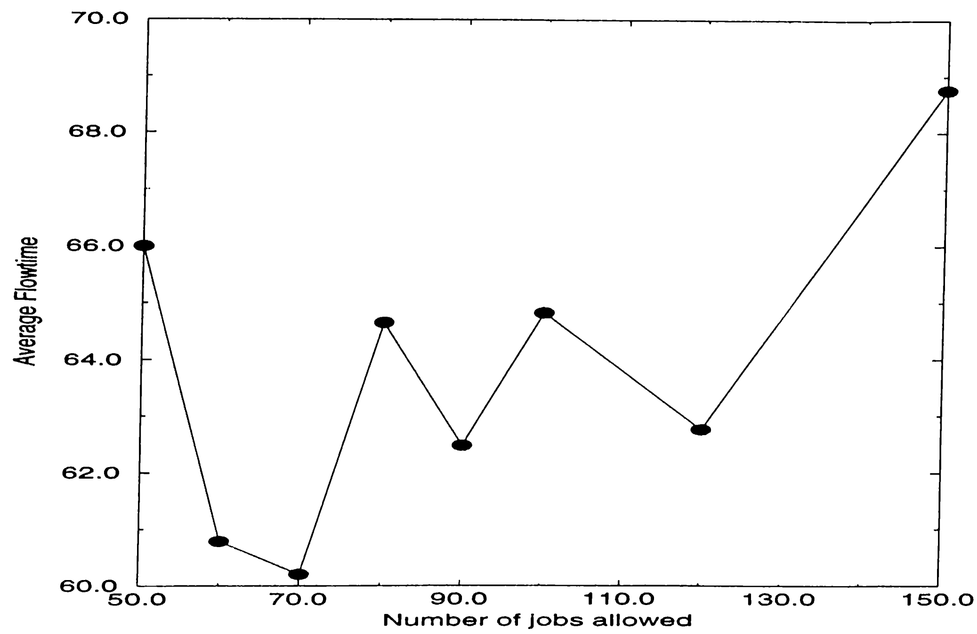

Figure 4.14: Mean Flowtime versus number of jobs allowed (For Aggregate Loading (per.) with SPT dispatching rule under high machine, transporter utilization, and loose due dates)

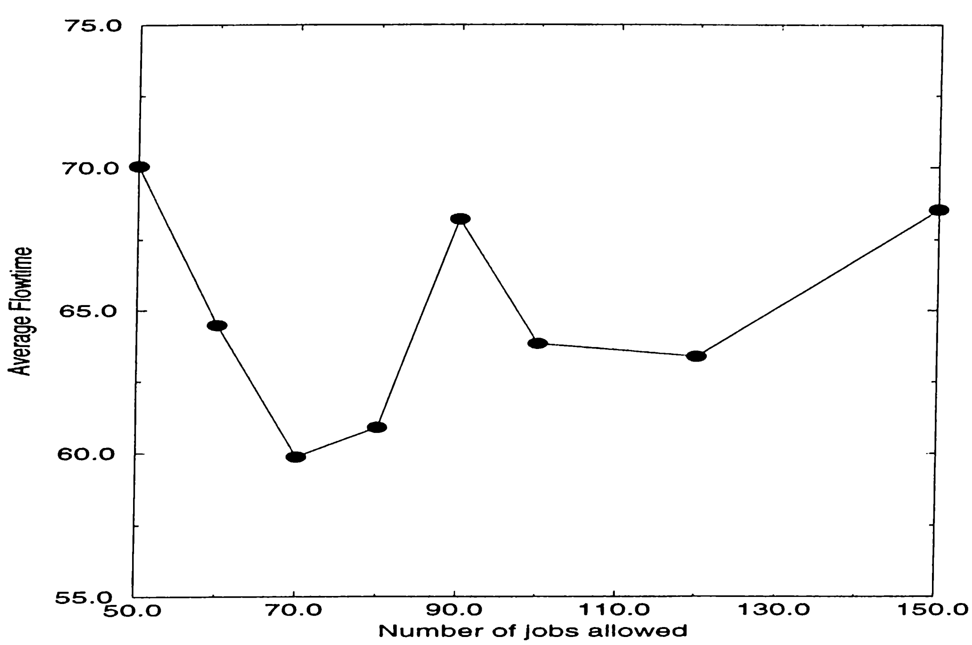

Figure 4.15: Mean Flowtime versus number of jobs allowed (For Aggregate Loading (per.) with MOD dispatching rule under high machine, transporter utilization, and loose due dates)

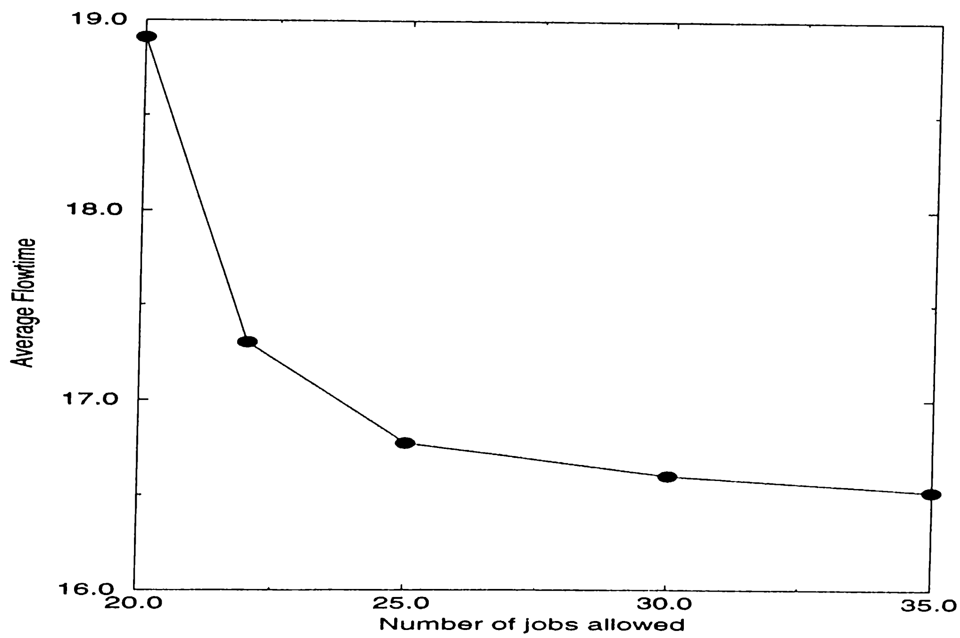

Figure 4.16: Mean Flowtime versus number of jobs allowed (For Aggregate Loading (per.) with SPT dispatching rule under low machine, transporter utilization, and loose due dates)

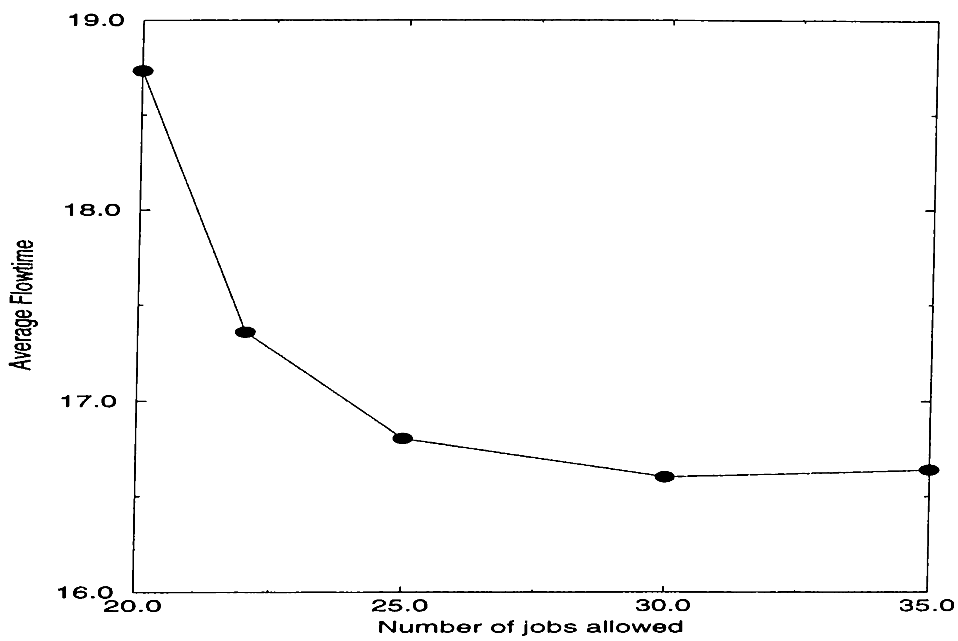

Figure 4.17: Mean Flowtime versus number of jobs allowed (For Aggregate Loading (per.) with MOD dispatching rule under low machine, transporter utilization, and loose due dates)

4.4 Workcenter Information Based Loading

Figures 4.18-4.21 show the mean flowtime performances of the workcenter information based loading under loose due dates. Detailed results are given in Tables A.23-A.30 in Appendix. For every experimental condition, system performance was evaluated for different load levels. Note that the load level is the unique parameter of this release mechanism. For high utilization case, we tested 8 different load levels. These are 1.1, 1.25, 1.5, 2, 3, 4, 5, 6. And for low utilization case, 6 different values were tried. These are 0.5, 2, 4, 6, 8, 16.

Again, we obtained U-shaped behaviour (Figures 4.18-4.19) for the mean flowtime measure under high utilization rates. We also observed that the minimum mean flowtime achieved by WIBL is smaller than the mean flowtime value found by the immediate release. As given in Table 4.3, this difference is found significant. For low utilization, setting the load level to small values increases the mean flowtime. In otherwords, the mean flowtime does not improve as we reduce the level of load in the system.

At low utilization rates, mean tardiness, percent tardy, mean lateness and time in system steadily increase as the load level is reduced. However, the U-shaped behaviour was observed for these measures under high utilization rates. Increasing the load level caused increased time in the shop because the number of jobs in the shop increases. Standard deviation of WIP in the shop also increased for large values of load level. Smaller mean absolute deviations were observed for increasing the load level under tight due dates and by decreasing the load level under loose due dates with low utilization rates. For the high utilization rates, the mean absolute deviation was small for small values of the mean flowtime under tight due dates and for large values of the mean flowtime under loose due dates. It was also observed that time in FGI is large for small mean flowtime values as expected.

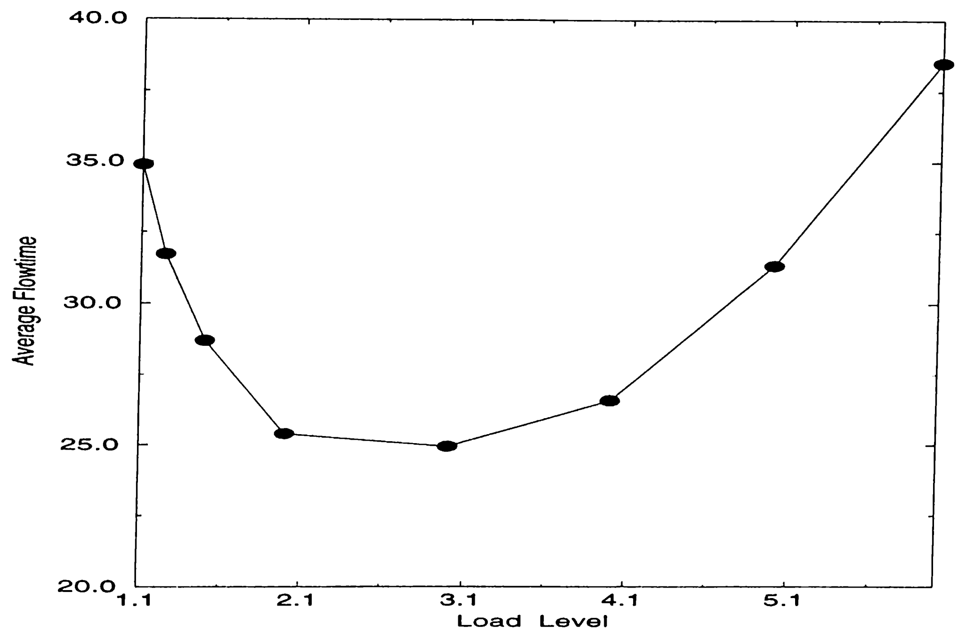

Figure 4.18: Mean Flowtime versus load level (For Workcenter Information Based Loading (cont.) with SPT dispatching rule under high machine, transporter utilization, and loose due dates)

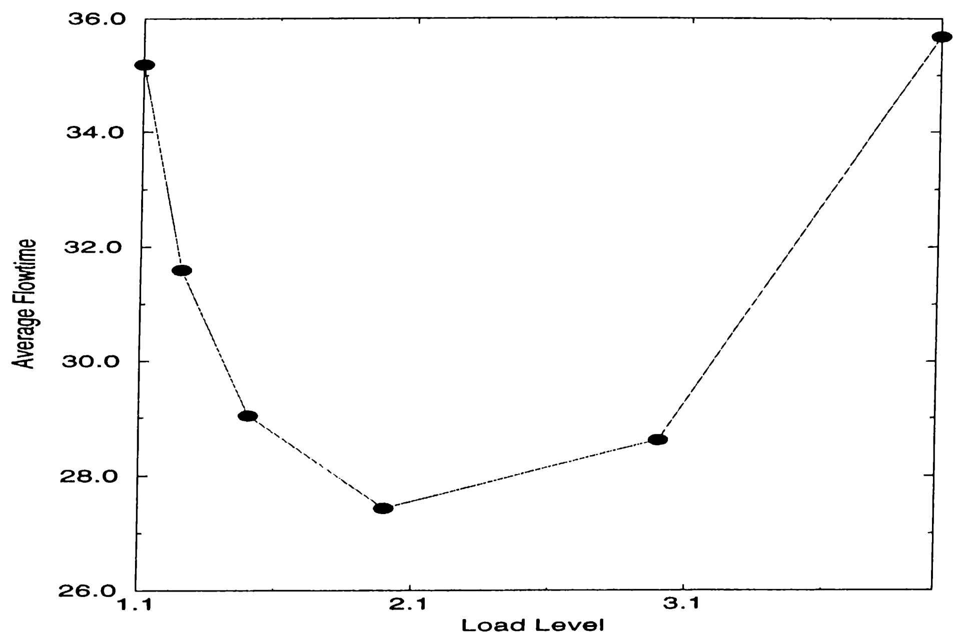

Figure 4.19: Mean Flowtime versus load level (For Workcenter Information Based Loading (cont.) with MOD dispatching rule under high machine, transporter utilization, and loose due dates)

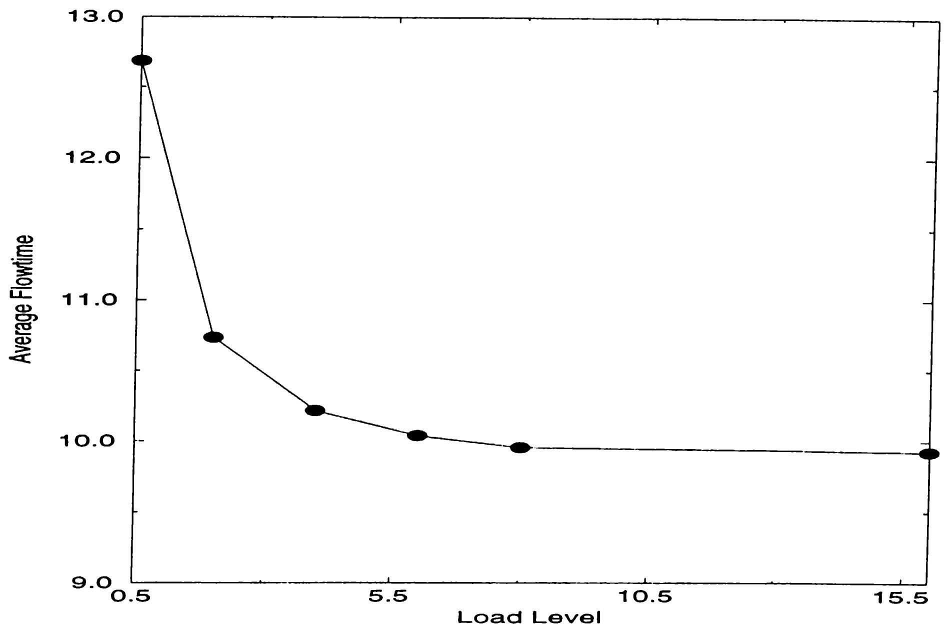

Figure 4.20: Mean Flowtime versus load level (For Workcenter Information Based Loading (cont.) with SPT dispatching rule under low machine, transporter utilization, and loose due dates)

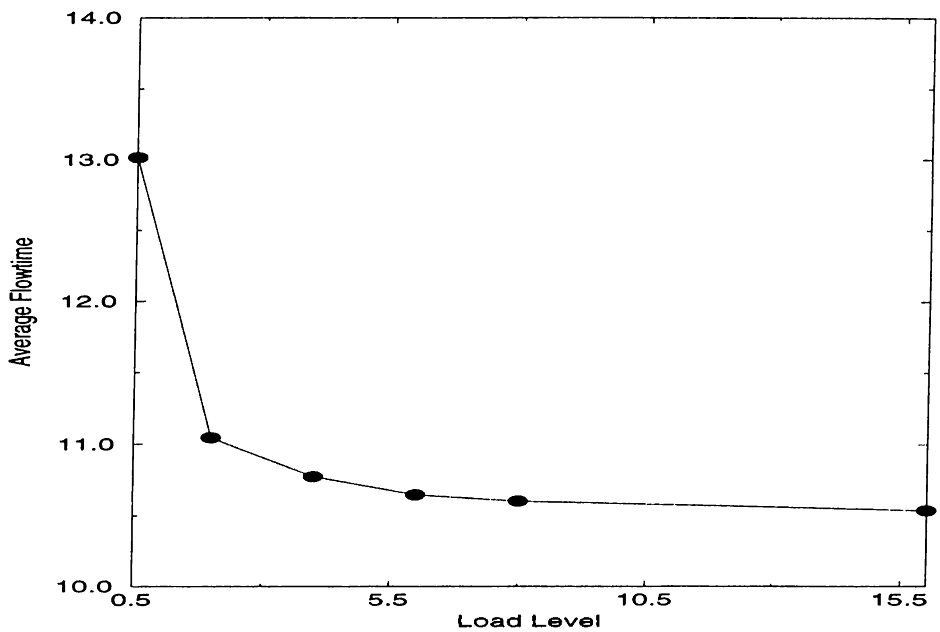

Figure 4.21: Mean Flowtime versus load level (For Workcenter Information Based Loading (cont.) with MOD dispatching rule under low machine, transporter utilization, and loose due dates)

Due date tightness= loose , Dispatching rule= SPT					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
19.572	31.683	7.085	2.76	0.012	(4.74,34.40)

Due date tightness= tight , Dispatching rule= SPT					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
14.863	25.735	5.754	2.58	0.018	(2.82,26.91)

Due date tightness= loose , Dispatching rule= MOD					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
16.716	26.009	5.816	2.87	0.0097	(4.54,28.89)

Due date tightness= tight , Dispatching rule= MOD					
Mean	St. deviation	SE mean	T	P value	95.0% C.I.
20.988	30.915	6.913	3.04	0.0068	(6.52,35.46)

Table 4.3: Paired t-test results for IMR and Workcenter Information Based Loading. Machine and transporter utilizations are high.

4.5 Finite and Infinite Loading

According to the infinite loading, there are two parameters (k_1 and k_2) to be estimated given in equation 3.1. In our study, these parameters were determined as a result of regression analysis. We use different k_1 and k_2 values for each experimental condition. Their current estimates are listed in Table 4.4. For example, under high utilization, loose due dates and SPT dispatching rule k_1 is 0.452 and k_2 is 1.205. And, under high utilization, loose due dates, MOD dispatching rule k_1 is 2.28 and k_2 is 1.08. We should note that the decrease from 1.205 to 1.08 for k_2 value compansates the increase of k_1 from 0.452 to 2.28 for this experimental condition. So, if the Q_i values are the same, we obtain approximately the same flowtime estimator for SPT and MOD rules. To get these estimates we collected data based on 1200 observations. Each observation includes actual flow time of the job, job characteristics and shop status information observed when the job received. Then we fit linear regression models [33][12] to the data sets.

Table 4.5 presents the k values used in equation 3.2 at forward finite loading. These values were also determined as a result of regression analysis.

4.6 Comparison of the Release Mechanisms

In this section, we compare all the release mechanisms discussed above. The analysis of variance and Duncan's test results for the mean flowtime measure are presented in the section. All two-way, three-way interactions and the four-way interaction are considered in the analysis of variance. Levels of the main factors (release mechanism, utilization, dispatching rule, due date tightness) considered are given in Table 4.7.

In all of the following analysis, we set the parameters of CAGG, PAGG and WIBL as follows: For CAGG and PAGG, we tested different number of jobs allowed into the shop values. And we choosed the number of jobs allowed

Machine and transporter utilization	Due date tightness	Dispatching rule	k_1	k_2
Low	Loose	SPT	1.91	0.55
Low	Tight	SPT	1.91	0.55
High	Loose	SPT	0.452	1.205
High	Tight	SPT	0.452	1.205
Low	Loose	MOD	1.92	0.6
Low	Tight	MOD	2.18	0.45
High	Loose	MOD	2.28	1.08
High	Tight	MOD	0.53	1.22

Table 4.4: Values of the planning factors used in infinite loading.

Machine and transporter utilization	Due date tightness	Dispatching rule	k
Low	Loose	SPT	2.76
Low	Tight	SPT	2.76
High	Loose	SPT	12.69
High	Tight	SPT	12.69
Low	Loose	MOD	2.94
Low	Tight	MOD	2.86
High	Loose	MOD	14.91
High	Tight	MOD	14.78

Table 4.5: Values of the planning factors used in forward finite loading.

value, which gave the best result for the corresponding performance measure, among the ones tested. Similarly, for WIBL, we tested different load levels. And we choosed the load level, which gave the best result for the corresponding performance measure, among the ones tested.

Note that we did not tested the performance of CINF, PINF and FFIN by using different k_1, k_2, k values for a given experimental condition. These values are fixed for each experimental condition.

For interval release (IR), in the following analysis, we used the results found when period length equal to 8 hours.

The analysis of variance (ANOVA) for the mean flowtime performance measure is given in Table 4.6. In this table, the source is significant if it has a probability value smaller than 0.05 in the column named as "Pr gt F". We show the source of variation due to blocking (or replications) as **B** in the analysis. The results indicated that main effects of all the factors other than the dispatching rules are significant. Moreover, all two-way interactions of utilization, due date tightness and release mechanisms are statistically significant. The three-way interaction of utilization, tightness and release mechanisms is also found significant on the mean flowtime criterion.

We also apply Duncan's multiple range test for the main effects of the factors. The results are given in Table 4.7. In this table, the levels which are statistically different are shown with the same letter. N stands for the number of observations in the corresponding level. The results indicated that CAGG and WIBL are the best ORR mechanisms and PINF is the worst release rule for the mean flowtime criterion. PINF, CINF, FFIN perform worse than other release methods for mean flowtime measure. These mechanisms try to finish the jobs on time. They do not control the load level in the shop. The jobs are kept in the pool longer durations. And the time in the shop is large because of the high congestion in the shop. There is no statistical difference between the dispatching rules. Increasing the load level and using loose due dates adversely affect the system performance. High load level increases the time in the shop and overall mean flowtime in the system increases. When the due dates are

Source	DF	Sum of Squares	F Value	Pr gt F
Model	82	3782904.14	101.94	0.0001
Error	1197	541701.13		
Source	DF	Anova SS	F Value	Pr gt F
B	19	349066.41	40.60	0.0001*
U	1	1413458.65	3123.33	0.0001*
T	1	101294.65	223.83	0.0001*
D	1	717.70	1.59	0.2082
R	7	894091.29	282.24	0.0001*
U*T	1	73084.50	161.50	0.0001*
U*D	1	884.43	1.95	0.1624
U*R	7	634857.88	200.41	0.0001*
T*D	1	99.95	0.22	0.6385
T*R	7	176134.65	55.60	0.0001*
D*R	7	3702.49	1.17	0.3178
U*T*D	1	116.50	0.26	0.6120
U*T*R	7	130933.20	41.33	0.0001*
U*D*R	7	3096.73	0.98	0.4460
T*D*R	7	667.53	0.21	0.9831
U*T*D*R	7	697.50	0.22	0.9808

B: Block effect, U: Utilization, T: Due date tightness
D: Dispatching rule, R: Release mechanism

Table 4.6: Analysis of Variance for Mean Flowtime

Factor: Release Mechanism (R)

Duncan Grouping	Mean	N	R
A	91.81	160	PINF
B	78.34	160	CINF
C	71.37	160	FFIN
D	45.33	160	IR
E	38.23	160	PAGG
F	27.13	160	IMR
G	20.13	160	CAGG
G	18.11	160	WIBL

Factor: Utilization (U)

Duncan Grouping	Mean	N	U
A	82.04	640	high
B	15.58	640	low

Factor: Dispatching Mechanism (D)

Duncan Grouping	Mean	N	D
A	49.56	640	SPT
A	48.06	640	MOD

Factor: Due Date Tightness (T)

Duncan Grouping	Mean	N	T
A	57.70	640	loose
B	39.91	640	tight

Table 4.7: Duncan's Multiple Range Test for Mean Flowtime

set loose, infinite loading mechanisms and forward finite loading rule keep the jobs in the pool longer durations, so the mean flowtime again increases.

ANOVA results for mean tardiness, mean absolute deviation and average number of jobs in the shop measures are also given in Tables B.1, B.3 and B.5 in Appendix. The related Duncan's multiple range tests for the performance measures are also given in Tables B.2, B.4 and B.6 in Appendix.

According to the ANOVA results of the mean tardiness measure, the main effects of all factors except the due date tightness are statistically significant. The due date tightness does not have a significant effect because both infinite loading mechanisms and the forward finite loading finish the jobs around their due dates. So most of the jobs become tardy under both tight and loose due date conditions if we use these release mechanisms. Also, the two-way interactions of the factors except the due date tightness-dispacthing mechanism and the release mechanism-dispatching mechanism interactions are effective on the performance measure. The three-way interaction of utilization, due date tightness and the release mechanisms is found significant.

Duncan's multiple range test showed that CAGG, WIBL and IMR are the best mechanisms in terms of mean tardiness measure. PINF was the worst among the release mechanisms. MOD was found to be better than SPT in terms of mean tardiness measure. In general, the system performance is adversely effected at higher values of utilization rates. No statistical difference is found between due date tightness levels. This is because of the fact that infinite loading mechanisms and finite forward loading finish the jobs closed to their due dates irrespective of due date tightness.

The main effects of the factors are also significant for the mean absolute deviation measure. Two-way interaction between due date tightness and dispatching mechanism, and three-way interaction of utilization, due date tightness and dispatching mechanism are not significant. All other two-way and three-way interactions and the four-way interaction are found to be significant on the sytem performance.

According to Duncan grouping, PAGG, IR and FFIN are the best mechanisms for the mean absolute deviation measure. However their performances are not statistically distinguishable. Duncan's test results also showed that PINF performs worst. Note that we might obtain better results for infinite loading mechanisms and forward finite loading if we had tested different planning factors (k_1, k_2, k) for each experimental condition. Moreover, the mean absolute deviation measure is worsened with loose due dates at the high utilization level. In these simulation experiments, MOD is found to be better than SPT dispatching mechanism.

Anova results for the average number of jobs in the shop measure showed that the main effects of all the factors except the dispatching mechanism are statistically significant. Also, all two-way interactions of utilization, due date tightness and the release mechanisms and three-way interaction of them are statistically significant.

According to Duncan grouping, there is no statistical difference between the performances of WIBL and CAGG mechanisms in terms of average number of jobs in the shop measure. These two release mechanisms perform better than the others. PINF is the worst among the others. There is no statistical difference between the dispatching mechanisms. The number of jobs in the shop is significantly larger for high utilization and loose due date cases.

For other performance measures, we made the following observations from the results of simulation experiments. CAGG and WIBL perform better than others for the percent tardy measure. IMR also performs well for the low utilization case. But PINF is the worst for this performance measure.

IR has the best grand average value (average of the results found in each experimental condition) among other mechanisms with respect to mean lateness performance. It is the best mechanism under the high utilization and loose due dates. CINF performs better for the low utilization case. All the mechanisms outperforms PINF in terms of the mean lateness.

CAGG and WIBL perform better in terms of the mean time in system measure. IMR shows identical performance as CAGG and WIBL for the low utilization case. PINF shows the worst performance among other mechanisms for average time in the system. PAGG is the best among the periodic mechanisms tested for this performance measure.

According to simulation experiments, WIBL is the best mechanism for the mean time in the shop measure. It is the best in terms of the average of the mean flowtime results found in each experimental condition and it also gives the best mean flowtime result in each experimental condition. PINF gives the largest mean time in the shop value among the other mechanisms. PAGG performs better than other periodic release mechanisms for this measure.

For the standard deviation of flowtime measure, it was found that IMR, CAGG and WIBL perform better than the other mechanisms under low utilization case. For the high utilization case, CAGG gives smaller standard deviation values. In general, PINF is the worst for the standard deviation of flowtime measure. PAGG performs better among the periodic mechanisms.

In terms of standard deviation of number of jobs in the shop measure, CAGG performs better than other rules. WIBL is slightly worse policy than CAGG for this measure. CINF is the worst of the release mechanisms tested in this study. Note that CINF does not control the load level in the shop. So high standard deviation of number of jobs in the shop values were obtained for this mechanism. But PAGG gives better results among the periodic release mechanisms.

Chapter 5

Proposed ORR Method

In this chapter we propose a new release mechanism. This release mechanism aims to finish the jobs at their due dates. We also present a modified version of the proposed release mechanism designed for the mean flowtime measure. Moreover, the performance of the methods are compared with other ORR mechanisms.

It is expected that the release mechanisms, which do not consider the due dates of the jobs, should perform worse than the due date oriented release mechanisms for mean absolute deviation measure. But our simulation results showed that non-due-date oriented mechanisms perform better than due date oriented mechanisms for mean absolute deviation at high utilization rates. This suggests that it is not enough to consider only due dates of the jobs in the pool for minimizing the mean absolute deviation criterion.

We propose a release mechanism which considers both the due dates of the jobs and the load level in the shop. We expect that, by considering both the due dates and the load level, we can obtain better results for mean absolute deviation. Meantime, we should point out that the proposed method is a periodic release mechanism and the period lengths are set to 8.0 hours.

The proposed release mechanism (PRM) works as follows: At the beginning of each period, release times of the jobs are calculated using Equation 5.1. This equation is the same as Equation 3.1.

$$R_i = D_i - k_1 * n_i - k_2 * Q_i \tag{5.1}$$

where,

R_i = Release time of job i,
D_i = Due date of job i,
n_i = Number of operations in job i,
Q_i = Number of jobs on job i's routing.
k_1, k_2 = Planning factors.

The values of k_1 and k_2 used in each experimental condition are equal to the values of k_1 and k_2 used in CINF and PINF. Note that these values were obtained by regression analysis. The values of k_1 and k_2 for each experimental condition are given in Table 4.4. Here, Q_i includes the jobs in input queues of the machines on job i's routing, the jobs in output queues of other machines waiting to be transported to a machine on job i's routing and plus the jobs which are currently being transported to a machine on job i's routing. If the release time of the job is less than current time plus a *time fence*, we further check if the work in process limit of the workstations are exceeded by the release of that job or not. We use the time fence to identify the urgent jobs in the pool. If the release time of the job is greater than the current time plus the time fence, the job is returned to the pool and it is reevaluated at the beginning of the next period. In our experiments, we take the time fence as 16 hours.

The procedure of testing whether the work in process limits at the workstations are exceeded or not, is as follows: First we estimate the operational flowtimes by Equation 5.2.

$$F_{ij} = k_1 + k_2 * Q_{ij} \tag{5.2}$$

where,

F_{ij} = Flow time of j th operation of job i,
Q_{ij} = Number of jobs at the station where j th operation of job i will be performed
k_1, k_2 = Planning factors.

Note that the sum of operational flowtimes of a job gives the flowtime estimate of that job ($k_1 * n_i + k_2 * Q_i$). Having a uniform machine load helps us in using the same equation (Equation 5.2) for calculating the operational flowtimes. Again, Q_{ij} includes the jobs at the station where jth operation of job i will be performed, the jobs in output queues of other machines waiting to be transported to the station and the jobs which are currently being transported to the station. Flowtime estimate of that operation gives us the estimated time duration (or periods) at which the job will be at the corresponding station. We add the processing time of the operation to the corresponding workstation's WIP profile. The periods, whose WIP levels are increased, are the ones on which the flowtime estimate lies. Note that this procedure is repeated beginning from the first operation.

WIP profile of a workstation shows the amount of WIP which will be handled in the future periods at that workstation. WIP amount of a workstation is measured as the sum of the processing times of the jobs at the workstation. Processing time of an operation is added to the WIP amount of the workstation for the corresponding periods.

After updating the WIP levels, we check whether the new WIP amounts at the WIP profiles exceeds the prespecified WIP limit for each workstation in every period. If the limit is exceeded in at least one period for any workstation, the job is returned to the pool. Note that this job will be reevaluated at the beginning of the next period.

If the limit is not exceeded in any of the periods for any workstation, then the following condition is tested: If the estimated release time falls before the current time, the job is released to the shop at the current time. If the estimated release time is after the current time, the release date of the job is frozen. In this case, the job is released to the shop exactly at its release time.

For keeping the WIP profile up-to-date, we modify the WIP profile whenever an operation is finished. In this case we subtract the operation time of the current and the following operations from the WIP profile. Then we estimate the flowtimes of the operations beginning from the next operation and increase the WIP levels by the processing times of the operations for the corresponding periods.

The steps of the proposed method is also summarized as follows:

1. Calculate the release time of the job.

2. If the release time of the job is less than current time plus the time fence, go to the step 3. Otherwise, return the job to the pool and go to the step 1 by considering the next job in the pool. If all the jobs in the pool have been evaluated, then stop.

3. Calculate the operational flowtimes of the job.

4. Modify the WIP profiles of the workstations by adding the processing times of the operations to the corresponding periods' load levels.

5. If the WIP limit is not exceeded in any of the periods of the WIP profiles maintained for each workstation, go to step 6. Otherwise, return the job to the pool and go to the step 1 by considering the next job in the pool. If all the jobs in the pool have been evaluated, then stop.

6. If the release time of the job is less than the current time, release the job immediately. Otherwise, freeze the release time of the job and release the job exactly at this release time.

7. Go to the step 1 by considering the next job in the pool. If all the jobs in the pool were evaluated, then stop.

Simulation results for the proposed release mechanism are given in Tables A.34-A.41. For every condition, the experiments are repeated for varying values of the WIP limit. Figure 5.1 shows the mean absolute deviation as a function of the WIP limit under high utilization and loose due dates using the SPT dispatching rule. For high utilization case, changes of mean absolute deviation by the WIP limit draw a U-shaped curve. But it decreases as we increase the WIP limit for the low utilization case (Figure 5.2).

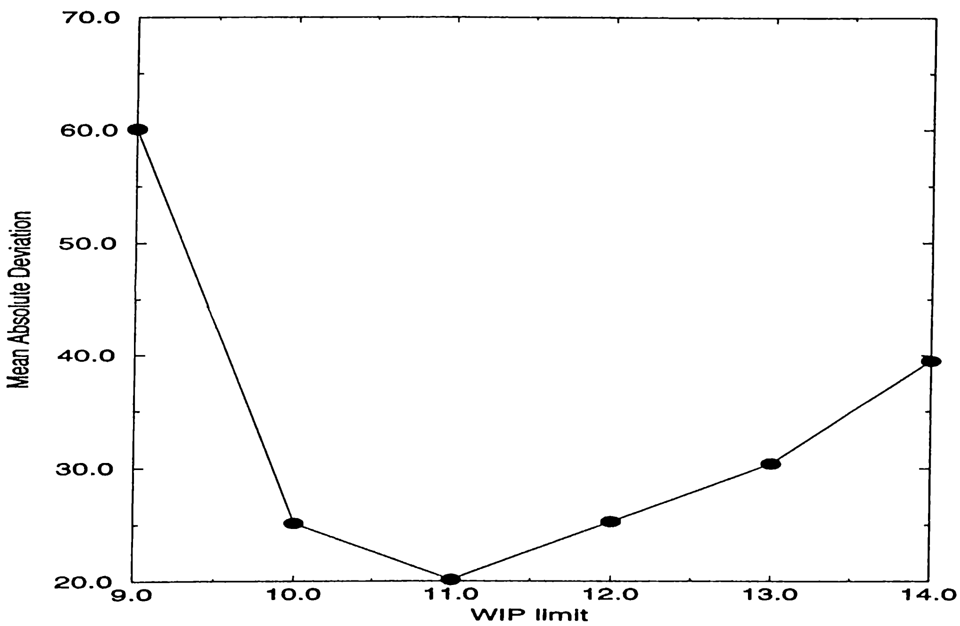

Figure 5.1: Mean Absolute Deviation versus WIP limit (For PRM with SPT dispatching rule under high machine, transporter utilization, and loose due dates)

We compare the performance of the proposed method with the best performers (i.e., ORR mechanisms found best in Chapter 4) at each experimental condition for mean absolute deviation, mean lateness and mean flowtime measures. As given in Tables 5.1-5.3, bold faced numbers give the best results found by the release mechanisms including PRM. Bold faced number with asterisk (*) shows that the result is significant at $\alpha = 0.05$. We also used the paired t-test for identifying the statistically best policy between PRM and the best rule found before. Tables 5.7-5.9 show these paired t-test results. According to Tables 5.1-5.3, the following observations can be made:

1. PRM performs well for the mean absolute deviation measure at high utilization rates. But it is statistically better than other mechanisms

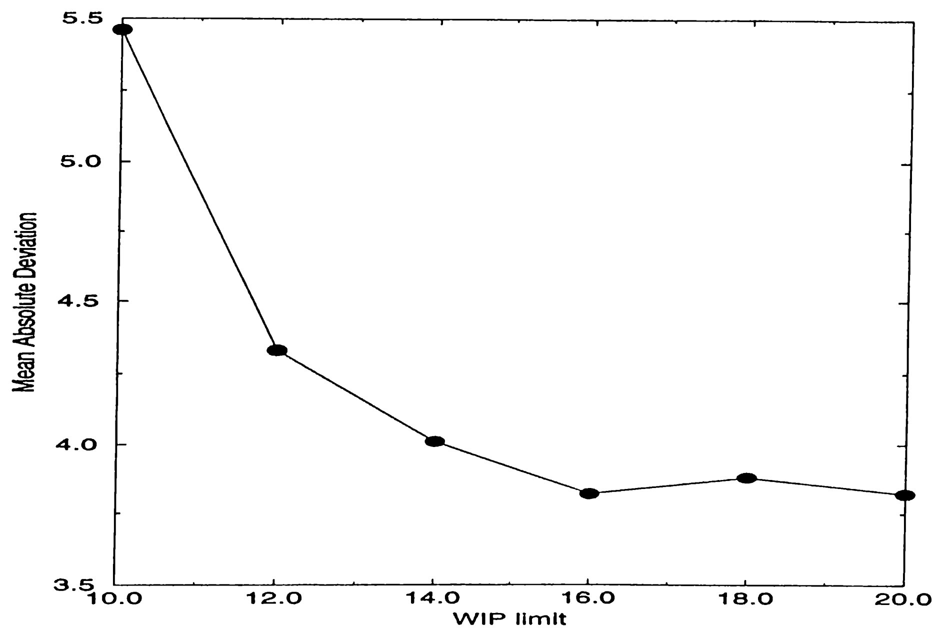

Figure 5.2: Mean Absolute Deviation versus WIP limit (For PRM with SPT dispatching rule under low machine, transporter utilization, and loose due dates)

under high utilization and loose due dates. As can be seen from the results, there is no need to contol the load level in the shop for low utilization cases. Because CINF, which does not control the load level in the shop, seems to perform better.

2. PRM performs statistically better than the best rule (IR) found before in terms of mean lateness under high utilization and loose due dates.

3. PRM performs statistically worse than the best ORR mechanism found in Chapter 4 for mean flowtime measure. This is normal, because the aim of our rule is to finish the jobs on time, not to minimize the mean flowtime. Use of PRM increases the time in the pool values, so we obtain large mean flowtime values.

Dispatching rule	Utilization	Due date tightness	Best result	PRM
SPT	high	loose	63.14 (PAGG)	**20.13***
SPT	high	tight	30.61 (CAGG)	**22.26**
MOD	high	loose	54.35 (IR)	**19.23***
MOD	high	tight	25.97 (CAGG)	**22.93**
SPT	low	loose	**3.14*** (CINF)	3.82
SPT	low	tight	**2.91*** (CINF)	4.86
MOD	low	loose	**2.71*** (CINF)	3.77
MOD	low	tight	**2.43*** (CINF)	4.73

Table 5.1: Comparison of the proposed release mechanism with other rules for mean absolute deviation

Dispatching rule	Utilization	Due date tightness	Best result	PRM
SPT	high	loose	−42.2 (IR)	**17.62***
SPT	high	tight	**8.81** (PAGG)	20.43
MOD	high	loose	−44.7 (IR)	**12.75***
MOD	high	tight	**−3.1*** (CAGG)	21.11
SPT	low	loose	**0.41*** (CINF)	2.47
SPT	low	tight	**0.93*** (CINF)	4.39
MOD	low	loose	**0.49*** (CINF)	2.27
MOD	low	tight	**0.79*** (CINF)	4.13

Table 5.2: Comparison of the proposed release mechanism with other rules for mean lateness

Dispatching rule	Utilization	Due date tightness	Best result	PRM
SPT	high	loose	**24.94*** (WIBL)	133.07
SPT	high	tight	**25.36*** (WIBL)	72.90
MOD	high	loose	**27.43*** (WIBL)	128.15
MOD	high	tight	**26.53*** (WIBL)	73.56
SPT	low	loose	**9.90*** (IMR)	25.21
SPT	low	tight	**9.88*** (IMR)	18.73
MOD	low	loose	**10.55*** (IMR)	25.01
MOD	low	tight	**10.35*** (IMR)	18.46

Table 5.3: Comparison of the proposed release mechanism with other rules for mean flowtime

Next, we modified the proposed release method to minimize the mean flowtime. This modified version does not consider the due dates of the jobs. The release decisions are made at the beginning of each period. All the jobs in the pool are candidates for releasing. First we calculate the operational flowtimes of the job using Equation 5.2. Then the WIP levels of the relevant workstations for corresponding periods are updated for the WIP profile which we maintain. The job is released to the shop immediately if it does not exceed the WIP limit in any of the periods for each workstation.

Otherwise, the job is returned to the pool and it is reevaluated at the beginning of the next period. For keeping the WIP profile up-to-date, the profile is also modified whenever an operation is finished. In this case we subtract the operation times of the current and the following operations from the WIP profile. Then we calculate the flowtime estimates for the operations starting from the next operation. We increase the WIP levels at the WIP levels by using these flowtime estimates and the processing time information of the operations.

The steps of the modified PRM can be summarized as follows:

1. Calculate the operational flowtimes of the job.
2. Modify the WIP profiles of the workstations by adding the processing times of the operations to the corresponding periods' load levels.
3. If the WIP limit is not exceeded in any of the periods of the WIP profiles maintained for each workstation, go to step 4. Otherwise, return the job to the pool and go to the step 1 by considering the next job in the pool. If all the jobs in the pool have been evaluated, then stop.
4. Release the job immediately.
5. Go to the step 1 by considering the next job in the pool. If all the jobs in the pool have been evaluated, then stop.

Simulation results of this release method (modified PRM) are given in Tables A.42-A.45 in Appendix. We tested the modified PRM for different interval lengths (e.g., 2,4 and 6 hours) at each experimental condition. For the high utilization case, we set the WIP limit to 8.0 hours. The WIP limit was set to 15.0 hours for the low utilization level.

Figure 5.3 shows the change of the mean flowtime by the interval length for SPT dispatching rule under the high utilization and loose due dates. As shown in the figure, the mean flowtime decreases as the interval length is shorten. Similar observation is made for the low utilization case (Figure 5.4).

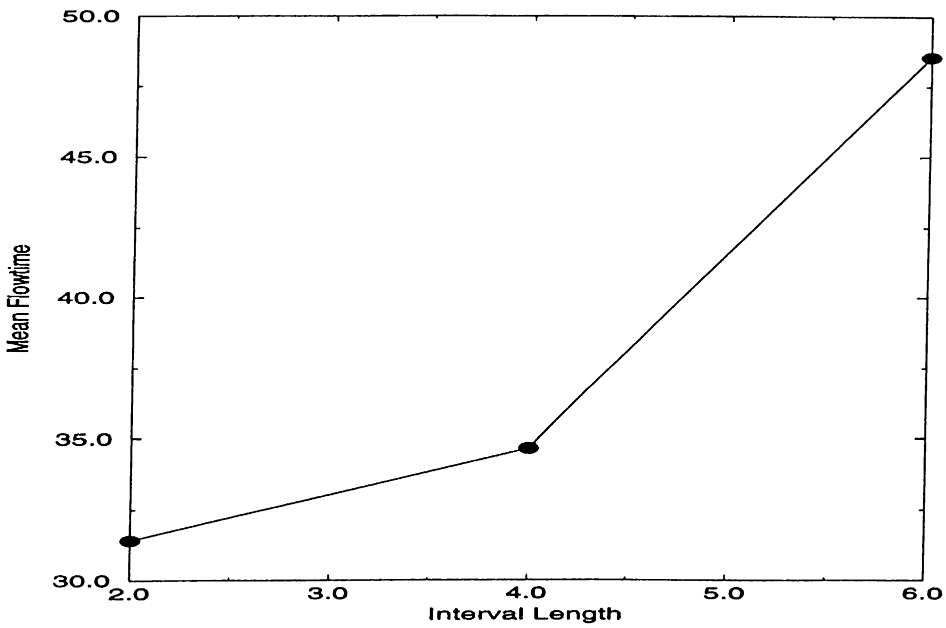

Figure 5.3: Mean Flowtime versus Interval Length (For the modified PRM with SPT dispatching rule under high machine, transporter utilization, and loose due dates)

We also compare the performance of the modified PRM with the best performers of each experimental condition in terms of mean absolute deviation, mean lateness and mean flowtime measures in Tables 5.4-5.6. Again the methods with the best performance are shown in bold face, and asterisk is used to indicate statistical significance. The paired t-test results are given in Tables 5.10-5.12. From the analysis of the results we make the following observations:

1. Modified PRM gives better results for mean absolute deviation measure under high utilization and tight due dates, however its performance is not statistically better.

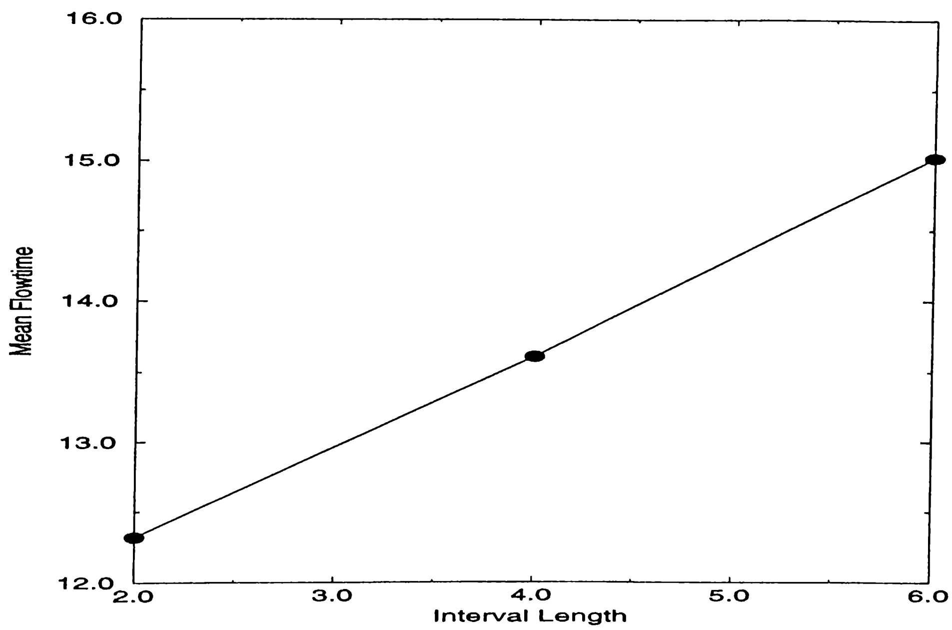

Figure 5.4: Mean Flowtime versus Interval Length (For the modified PRM with SPT dispatching rule under low machine, transporter utilization, and loose due dates)

2. Modified PRM gives statistically better results for mean lateness, under SPT dispatching rule and tight due dates.

3. Modified PRM gives better results than PRM in terms of mean flowtime. But the results are not statistically better than the best results found before.

Although, the performance of modified PRM for mean flowtime is statistically worst than the best results found before, it performs better than immediate release (IMR) under high utilization levels. Paired t-test results are given in Table 5.13. The results indicate that it is definitely better than immediate release for these conditions.

Dispatching rule	Utilization	Due date tightness	Best result	modified PRM
SPT	high	loose	**63.14*** (PAGG)	71.44
SPT	high	tight	30.61 (CAGG)	**26.26**
MOD	high	loose	**54.35*** (IR)	76.64
MOD	high	tight	25.97 (CAGG)	**25.05**
SPT	low	loose	**3.14*** (CINF)	9.53
SPT	low	tight	**2.91*** (CINF)	4.68
MOD	low	loose	**2.71*** (CINF)	9.40
MOD	low	tight	**2.43*** (CINF)	4.61

Table 5.4: Comparison of the modified PRM with other rules for mean absolute deviation

Dispatching rule	Utilization	Due date tightness	Best result	modified PRM
SPT	high	loose	**−42.2*** (IR)	−66.78
SPT	high	tight	8.81 (PAGG)	**−2.09***
MOD	high	loose	**−44.7*** (IR)	−73.21
MOD	high	tight	**−3.1** (CAGG)	−6.36
SPT	low	loose	**0.41*** (CINF)	−7.71
SPT	low	tight	0.93 (CINF)	**−0.68***
MOD	low	loose	**0.49*** (CINF)	−7.54
MOD	low	tight	0.79 (CINF)	**0.63**

Table 5.5: Comparison of the modified PRM with other rules for mean lateness

Dispatching rule	Utilization	Due date tightness	Best result	modified PRM
SPT	high	loose	**24.94*** (WIBL)	31.42
SPT	high	tight	**25.36*** (WIBL)	32.55
MOD	high	loose	**27.43*** (WIBL)	30.45
MOD	high	tight	**26.53*** (WIBL)	32.02
SPT	low	loose	**9.90*** (IMR)	12.32
SPT	low	tight	**9.88*** (IMR)	12.23
MOD	low	loose	**10.55*** (IMR)	12.35
MOD	low	tight	**10.35*** (IMR)	12.29

Table 5.6: Comparison of the modified PRM with other rules for mean flowtime

Finally, we investigated the change of mean flowtime by the WIP limit for modified PRM. In these simulation runs, the interval length was set to 2.0 hours. For high utilization, loose due dates and SPT dispatching rule, we obtained the results given in Table 5.14. Figure 5.5 show the change of mean flowtime by the WIP limit. The best result found before for this experimental condition was 24.94. It was found by using WIBL. This value is less than the best result found by modified PRM (26.11). However, as shown in Table 5.15, the difference between these results is not significant.

Dispatching rule	Utilization	Due date tightness	Mean	SE mean	T	P value
SPT	high	loose	43.01	6.21	7.17	0.0001
SPT	high	tight	8.35	1.19	1.98	0.0614
MOD	high	loose	35.12	7.43	4.73	0.0001
MOD	high	tight	3.04	4.79	0.63	0.5339
SPT	low	loose	-0.68	0.04	-15.13	0.0001
SPT	low	tight	-1.94	0.07	-25.18	0.0001
MOD	low	loose	-1.06	0.04	-21.68	0.0001
MOD	low	tight	-2.30	0.08	-28.20	0.0001

Table 5.7: Paired t-test results of PRM for mean absolute deviation measure

Dispatching rule	Utilization	Due date tightness	Mean	SE mean	T	P value
SPT	high	loose	-59.90	7.89	-7.58	0.0001
SPT	high	tight	-11.61	5.80	-2.00	0.0598
MOD	high	loose	-57.45	7.06	-8.13	0.0001
MOD	high	tight	-24.29	4.74	-5.11	0.0001
SPT	low	loose	-2.05	0.06	-30.28	0.0001
SPT	low	tight	-3.46	0.07	-45.68	0.0001
MOD	low	loose	-1.77	0.05	-34.25	0.0001
MOD	low	tight	-3.33	0.07	-43.56	0.0001

Table 5.8: Paired t-test results of PRM for mean lateness measure

Dispatching rule	Utilization	Due date tightness	Mean	SE mean	T	P value
SPT	high	loose	-108.13	1.17	-92.42	0.0001
SPT	high	tight	-47.53	0.97	-48.67	0.0001
MOD	high	loose	-100.73	0.85	-118.25	0.0001
MOD	high	tight	-47.03	1.86	-25.28	0.0001
SPT	low	loose	-15.30	0.10	-150.19	0.0001
SPT	low	tight	-8.85	0.08	-105.34	0.0001
MOD	low	loose	-14.45	0.08	-162.41	0.0001
MOD	low	tight	-8.11	0.07	-115.23	0.0001

Table 5.9: Paired t-test results of PRM for mean flowtime measure

Dispatching rule	Utilization	Due date tightness	Mean	SE mean	T	P value
SPT	high	loose	-6.72	2.52	-2.65	0.0156
SPT	high	tight	4.34	2.78	1.55	0.1353
MOD	high	loose	-22.29	4.12	-5.40	0.0001
MOD	high	tight	0.92	2.34	0.39	0.6978
SPT	low	loose	-6.39	0.15	-39.99	0.0001
SPT	low	tight	-1.76	0.05	-30.21	0.0001
MOD	low	loose	-6.68	0.16	-39.65	0.0001
MOD	low	tight	-2.17	0.05	-39.57	0.0001

Table 5.10: Paired t-test results of modified PRM for mean absolute deviation measure

Dispatching rule	Utilization	Due date tightness	Mean	SE mean	T	P value
SPT	high	loose	24.49	6.82	3.59	0.0019
SPT	high	tight	10.90	4.74	2.30	0.0329
MOD	high	loose	28.51	5.77	4.93	0.0001
MOD	high	tight	3.18	4.09	0.77	0.4465
SPT	low	loose	8.12	0.09	82.98	0.0001
SPT	low	tight	1.61	0.08	18.96	0.0001
MOD	low	loose	8.03	0.10	73.66	0.0001
MOD	low	tight	0.16	0.08	1.99	0.0605

Table 5.11: Paired t-test results of modified PRM for mean lateness measure

Dispatching rule	Utilization	Due date tightness	Mean	SE mean	T	P value
SPT	high	loose	-6.48	1.42	-4.56	0.0002
SPT	high	tight	-7.18	1.51	-4.73	0.0001
MOD	high	loose	-3.02	0.77	-3.87	0.0010
MOD	high	tight	-5.48	1.65	-3.31	0.0037
SPT	low	loose	-2.41	0.07	-32.05	0.0001
SPT	low	tight	-2.34	0.06	-37.95	0.0001
MOD	low	loose	-1.79	0.04	-36.35	0.0001
MOD	low	tight	-1.93	0.05	-34.81	0.0001

Table 5.12: Paired t-test results of modified PRM for mean flowtime measure

Dispatching rule	Utilization	Due date tightness	Mean	SE mean	T	P value
SPT	high	loose	13.09	5.84	2.23	**0.0373***
SPT	high	tight	7.67	4.50	1.70	**0.1048**
MOD	high	loose	13.69	5.46	2.50	**0.0214***
MOD	high	tight	15.50	5.70	2.71	**0.0136***

Table 5.13: Paired t-test results for IMR and modified PRM for mean flowtime measure

WIP limit	mean flowtime
8.0	31.42
7.0	27.15
6.0	26.11

Table 5.14: Change of mean flowtime by the WIP limit for the modified PRM under high utilization, loose due dates and SPT dispatching rule. (Interval length is 2.0 hours.)

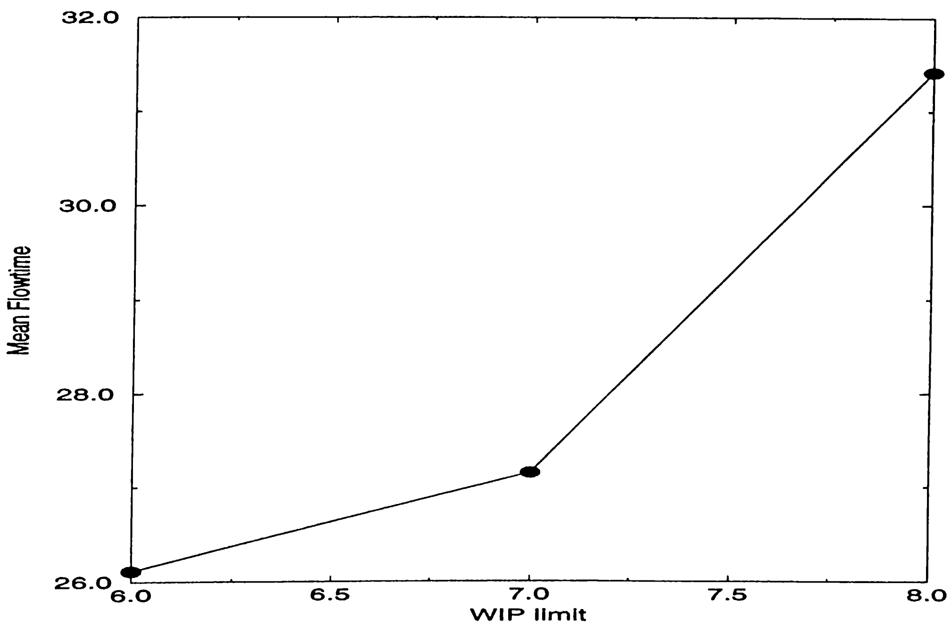

Figure 5.5: Mean Flowtime versus WIP limit (For the modified PRM with SPT dispatching rule under high machine, transporter utilization, and loose due dates)

Mean	SE mean	T	P value
-1.17	0.86	-1.36	0.1880

Table 5.15: Paired t-test result between WIBL and the modified PRM (WIP limit is 6.0 hours and period length is 2.0 hours.)

Chapter 6

Conclusion

In this study, we compared the performances of the ORR mechanisms in a job shop. The job shop includes finite buffer capacity and a material handling system. Early shipments are prohibited in the model. We also proposed a release mechanism and compared it with other methods.

A full factorial experimental design was developed to test the performances of the release mechanisms. Four factors (release mechanism, dispatching rule, machine and transporter utilization and due date tightness) were included in the analysis. Release mechanisms tested include four periodic and four continuous release mechanisms. Various performance measures were used to obtain a comprehensive comparison of the release methods.

We showed clearly the benefit of input regulation under high utilization levels for the mean flowtime measure. Note that this benefit has not been observed previously in the ORR literature.

It was observed that the use of small interval lengths improves the mean flowtime measure in the interval release (IR) mechanism. It was found that it is better to use immediate release than interval release for the mean flowtime measure.

For the mean flowtime measure, continuous release mechanisms, except continuous infinite loading (CINF), perform better than periodic versions of the release rules. It was also observed that release methods which do not consider the due dates of the jobs (IMR, IR, CAGG, PAGG, WIBL) perform better than due date oriented release methods (CINF, PINF, FFIN) for the mean flowtime measure. WIBL gave the best results for mean flowtime.

The release mechanisms which do not consider the due dates also outperformed the others for the average number of jobs in the shop measure. For this measure, WIBL shows the best performance.

For the mean tardiness measure, Duncan's test result indicated that non due date oriented mechanisms perform better. As it has been stated in the literature, MOD outperforms SPT for this measure.

It was observed that due date oriented methods perform better under low utilization levels for mean absolute deviation. However, they do not perform better than the rules which do not consider the due dates under high utilization levels. Note that we did not test different k_1 and k_2 for infinite loading methods and different k values for the forward finite loading method. We might obtain better mean absolute deviation values if we had tested the different planning factors for a given experimental condition.

It is also important to note that the performances of the tested ORR procedures might be significantly effected by the parameter selection process. The parameters are k_1 and k_2 in CINF, PINF and PRM methods, k in FFIN method, number of jobs allowed value in CAGG, PAGG methods, load level in WIBL mechanism, etc. So the users of these procedures should be very careful in deciding these parameters. Our results are only valid for the selected experimental conditions and parameter settings.

The ANOVA results revealed that the main effects of all the factors other than the dispatching rules are significant for mean flowtime measure. This shows that we obtain approximately the same mean flowtime values for SPT and MOD dispatching rules if we use ORR mechanisms. Due date tightness is significant for the mean flowtime measure because some of the ORR mechanisms (CINF, PINF, FFIN) try to finish the jobs on time and they do not control the level of load in the shop. We obtain high flowtime values for these mechanisms under loose due dates. Utilization level is also significant because we have large WIP level in the shop for high utilization case. Large WIP level in the shop causes an increase in mean flowtime.

The main effects of all factors are significant except the due date tightness is significant for the mean tardiness measure according to the ANOVA results. CINF, PINF and FFIN give large mean tardiness values irrespective of due date tightness. These mechanisms give large mean tardiness values because they try to finish the jobs at their due dates.

We also proposed a release mechanism (PRM) that aims to finish the jobs on time. It considers both due dates of the jobs and WIP levels in the shop. The results showed that the proposed method performs better for mean absolute deviation under high utilization. Its performance is also better for the mean lateness under high utilization and loose due dates. This means that both due dates of the jobs and the shop load should be considered to reduce mean absolute deviation under high utilization. However, the proposed release mechanism showed poor performance for the mean flowtime measure.

We modified the proposed release mechanism with the aim of minimizing the mean flowtime. The modified version (modified PRM) was tested for different interval lengths in the study. The results showed that the modified version outperformed immediate release (IMR) for the mean flowtime under high utilization levels. But WIBL outperformed the modified version under high utilization levels. It was also observed that IMR perform better than the modified version under low utilization levels.

We also tested the performance of modified PRM by using the WIP limit value of 6.0 hours and the interval length of 2.0 hours under high utilization, loose due dates and SPT dispatching rule. Even though the mean flowtime value found in this setting is slightly large than the value found by WIBL, the difference is not statistically significant.

The following further research topics can be suggested based on the analysis made in the thesis:

- All the machines have almost the same utilization levels in our simulation model. ORR mechanisms can be tested by using a job shop in which the machines have different utilization levels. Machine breakdown can also be considered to obtain a more realistic setting.

- The performance of the release rules tested can be evaluated by using a combined performance measure (i.e., a total cost including inventory holding and delivery costs)

- New flowtime estimation methods can be implemented for the proposed release mechanism. For example, the operational flowtimes can be estimated by using a finite loading method. By the use of finite loading methods, we can consider available shop capacity over time in the proposed method.

Appendix A

Tables

Machine and transporter utilizations	Low				High			
Due Date Tightness	Loose		Tight		Loose		Tight	
Dispatching Rule	SPT	MOD	SPT	MOD	SPT	MOD	SPT	MOD
mean flowtime	9.90	10.55	9.88	10.35	44.51	44.14	40.22	47.52
mean tardiness	0.088	0.078	0.42	0.37	6.00	1.71	12.72	14.87
percent tardy	5.22	5.17	19.49	20.25	8.92	8.13	20.00	29.69
mean lateness	-12.8	-12.1	-4.4	-3.9	-70.8	-71.2	-12.2	-4.9
absolute deviation	13.00	12.33	5.29	4.72	82.89	74.63	37.69	34.67
time in system	22.8	22.8	14.7	14.7	121.4	117.0	65.19	67.3
time in shop	9.42	10.06	9.39	9.87	43.51	43.16	39.26	46.50
time in pool	0.48	0.48	0.48	0.48	0.99	0.97	0.96	1.01
M/H time	1.62	1.64	1.62	1.63	1.97	1.98	1.95	2.00
time in IQ	2.96	3.27	2.94	3.18	6.58	6.64	6.43	6.81
blocking time	0.046	0.051	0.045	0.050	0.37	0.35	0.35	0.38
time in OQ	1.29	1.60	1.28	1.50	31.09	30.69	27.01	33.80
time in FGI	12.91	12.25	4.86	4.35	76.89	72.92	24.96	19.80
jobs in shop	10.97	11.69	10.93	11.46	62.93	62.63	56.86	67.25
std. of flowtime	6.02	6.87	6.02	6.43	40.23	34.64	36.15	39.44
std. of jobs in shop	4.29	4.70	4.24	4.55	12.02	12.77	11.63	12.92

Table A.1: Simulation results of Immediate Release

Machine and transporter utilizations	Low							
Due Date Tightness	Loose				Tight			
Dispatching Rule	SPT		MOD		SPT		MOD	
Interval Length	2.0	8.0	2.0	8.0	2.0	8.0	2.0	8.0
mean flowtime	12.29	16.52	12.33	16.59	12.24	16.45	12.30	16.44
mean tardiness	0.37	1.37	0.35	1.34	1.34	3.74	1.33	3.71
percent tardy	14.0	31.4	13.9	31.4	38.5	66.9	39.2	67.2
mean lateness	-10.4	-6.2	-10.4	-6.1	-2.0	2.1	-2.0	2.11
absolute deviation	11.17	8.97	11.11	8.81	4.76	5.35	4.69	5.30
time in system	23.10	24.11	23.09	24.07	15.67	18.07	15.66	18.04
time in shop	10.74	11.40	10.77	11.47	10.69	11.30	10.75	11.30
time in pool	1.54	5.11	1.55	5.12	1.55	5.15	1.55	5.14
M/H time	1.65	1.67	1.65	1.67	1.65	1.66	1.65	1.66
time in IQ	3.57	3.82	3.55	3.85	3.52	3.77	3.56	3.77
blocking time	0.06	0.12	0.06	0.11	0.06	0.12	0.06	0.11
time in OQ	1.95	2.29	2.00	2.32	1.94	2.24	1.97	2.25
time in FGI	10.80	7.59	10.76	7.47	3.42	1.61	3.35	1.59
jobs in shop	12.49	13.24	12.52	13.31	12.41	13.11	12.49	13.11
std. of flowtime	6.54	7.21	6.65	7.33	6.50	7.19	6.56	7.17
std. of jobs in shop	4.98	5.62	5.06	5.68	4.98	5.57	5.03	5.55

Table A.2: Simulation results of Interval Release

Machine and transporter utilizations	High							
Due Date Tightness	Loose				Tight			
Dispatching Rule	SPT		MOD		SPT		MOD	
Interval Length	2.0	8.0	2.0	8.0	2.0	8.0	2.0	8.0
mean flowtime	50.47	73.07	51.55	70.65	47.55	78.70	44.37	74.25
mean tardiness	6.38	13.10	2.54	4.82	15.16	36.51	10.69	31.03
percent tardy	10.0	17.8	11.7	21.3	28.7	52.4	32.5	58.3
mean lateness	-64.8	-42.2	-63.8	-44.7	-4.8	26.2	-8.0	21.8
absolute deviation	77.63	68.49	68.89	54.35	35.23	46.74	29.47	40.23
time in system	121.7	128.4	117.9	120.1	67.6	88.9	63.1	83.45
time in shop	48.39	66.96	49.49	64.55	45.50	72.61	42.34	68.22
time in pool	2.07	6.11	2.06	6.10	2.05	6.08	2.03	6.03
M/H time	2.03	2.12	2.03	2.10	2.02	2.13	2.01	2.10
time in IQ	7.02	7.90	7.02	7.71	6.97	7.88	6.88	7.68
blocking time	0.41	0.56	0.40	0.53	0.40	0.56	0.38	0.53
time in OQ	35.41	52.86	36.52	50.69	32.61	58.53	29.55	54.40
time in FGI	71.25	55.38	66.34	49.52	20.06	10.23	18.77	9.19
jobs in shop	70.06	96.13	71.61	92.85	65.86	104.0	61.33	97.85
std. of flowtime	41.86	61.94	37.53	48.28	38.85	69.31	32.52	59.42
std. of jobs in shop	13.10	14.86	13.82	15.79	12.49	15.51	12.72	14.69

Table A.3: Simulation results of Interval Release

Number of jobs allowed	25	30	35	40	50	60	70	80	90	120
mean flowtime	33.49	27.89	29.09	27.46	27.96	31.31	33.95	34.96	36.64	38.34
mean tardiness	2.32	1.01	1.13	0.72	0.50	0.81	1.22	1.34	1.77	2.41
percent tardy	8.91	5.54	5.77	4.39	3.75	4.98	5.98	6.25	7.14	7.59
mean lateness	-81.8	-87.4	-86.2	-87.9	-87.4	-84.0	-81.4	-80.3	-78.6	-77.0
absolute deviation	86.50	89.48	88.52	89.35	88.41	85.67	83.84	83.06	82.24	81.89
time in system	117.6	116.3	116.4	116.0	115.8	116.1	116.5	116.6	117.1	117.8
time in shop	15.10	16.83	18.34	19.37	21.79	24.26	26.91	28.41	30.31	34.64
time in pool	18.39	11.05	10.74	8.08	6.16	7.04	7.04	6.55	6.32	3.69
M/H time	1.79	1.82	1.85	1.86	1.89	1.92	1.93	1.93	1.93	1.95
time in IQ	5.23	5.49	5.71	5.79	5.97	6.15	6.24	6.28	6.29	6.40
blocking time	0.17	0.20	0.23	0.25	0.28	0.31	0.32	0.33	0.33	0.34
time in OQ	4.40	5.80	7.03	7.96	10.15	12.38	14.92	16.36	18.24	22.4
time in FGI	84.17	88.47	87.39	88.62	87.91	84.85	82.62	81.72	80.47	79.47
jobs in shop	22.10	24.60	26.78	28.27	31.78	35.33	39.16	41.33	44.12	50.38
std. of flowtime	12.71	13.66	14.83	15.77	18.17	20.02	23.34	24.49	26.67	30.41
std. of jobs in shop	3.06	4.22	5.17	5.98	6.77	7.38	7.79	8.34	8.87	9.44

Table A.4: Simulation results of Aggregate Loading(cont.) with SPT dispatching rule under high machine,transporter utilization, and loose due dates.

Number of jobs allowed	25	30	35	40	50	60	70	80	90	120
mean flowtime	33.92	28.58	27.73	28.01	29.75	30.43	31.68	33.13	32.52	35.43
mean tardiness	7.12	4.02	3.26	3.29	4.11	4.27	5.24	6.35	6.16	8.75
percent tardy	26.0	18.3	16.9	16.9	18.9	19.4	20.1	21.5	19.8	20.3
mean lateness	-18.5	-23.8	-24.7	-24.4	-22.7	-22.0	-20.8	-19.3	-19.9	-17.0
absolute deviation	32.80	31.95	31.28	31.05	30.97	30.61	31.31	32.07	32.31	34.55
time in system	59.6	56.50	55.7	55.7	56.6	56.7	57.7	58.8	58.6	61.2
time in shop	22.21	16.94	18.43	19.64	21.89	23.97	25.93	27.63	28.52	33.01
time in pool	18.72	11.64	9.29	8.37	21.89	6.45	5.74	5.49	3.99	2.41
M/H time	1.79	1.83	1.86	1.87	1.90	1.91	1.92	1.93	1.92	1.93
time in IQ	5.23	5.53	5.72	5.83	6.04	6.12	6.17	6.23	6.20	6.27
blocking time	0.17	0.21	0.23	0.25	0.28	0.30	0.31	0.32	0.31	0.33
time in OQ	4.48	5.86	7.11	8.18	10.16	12.13	14.02	15.65	16.57	20.97
time in FGI	25.68	27.92	28.01	27.76	26.85	26.33	26.06	25.72	26.14	25.79
jobs in shop	22.21	24.75	26.92	28.68	31.92	34.97	37.77	40.17	41.57	47.93
std. of flowtime	12.57	13.59	14.64	15.77	17.80	19.98	22.06	23.63	24.43	29.14
std. of jobs in shop	3.05	4.29	5.21	6.07	6.77	7.33	7.80	8.32	8.40	9.55

Table A.5: Simulation results of Aggregate Loading(cont.) with SPT dispatching rule under high machine,transporter utilization, and tight due dates.

Number of jobs allowed	25	30	35	40	50	60	70	80	90	120
mean flowtime	59.80	41.61	36.67	33.09	36.29	35.53	37.31	40.49	40.10	41.84
mean tardiness	7.87	3.38	2.02	1.13	1.12	0.66	0.79	0.84	0.58	0.67
percent tardy	21.8	11.4	8.18	5.74	5.74	4.28	4.63	5.17	4.69	5.57
mean lateness	-55.5	-73.7	-78.6	-82.2	-79.0	-79.8	-78.0	-74.8	-75.2	-73.5
absolute deviation	71.28	80.52	82.72	84.53	81.30	81.15	79.64	76.54	76.41	74.87
time in system	123.2	118.7	117.3	116.4	116.4	116.0	116.1	116.2	115.9	116.0
time in shop	16.54	18.35	20.00	21.48	24.87	27.10	29.01	32.10	33.64	38.24
time in pool	43.26	23.26	16.66	11.61	11.42	8.43	8.29	8.38	6.46	3.59
M/H time	1.82	1.86	1.89	1.90	1.94	1.95	1.96	1.97	1.98	1.98
time in IQ	5.55	5.79	5.96	6.10	6.34	6.44	6.43	6.56	6.61	6.62
blocking time	0.18	0.21	0.24	0.26	0.29	0.31	0.32	0.34	0.34	0.35
time in OQ	5.47	6.97	8.40	9.70	12.79	14.88	16.79	19.73	21.20	25.79
time in FGI	63.41	77.13	80.69	83.40	80.18	80.48	78.84	75.70	75.82	74.20
jobs in shop	24.15	26.70	29.09	31.22	36.13	39.33	42.14	46.60	48.85	55.53
std. of flowtime	16.22	16.73	18.01	19.51	23.05	25.10	26.91	29.43	29.99	32.07
std. of jobs in shop	1.27	3.21	4.74	5.87	7.06	8.16	8.75	9.30	9.97	10.80

Table A.6: Simulation results of Aggregate Loading(cont.) with MOD dispatching rule under high machine,transporter utilization, and loose due dates.

Number of jobs allowed	25	30	35	40	50	60	70	80	90	120
mean flowtime	49.27	36.21	33.99	32.08	32.12	33.03	34.59	36.79	38.15	38.14
mean tardiness	14.64	6.68	5.45	3.93	3.41	3.26	4.50	6.17	7.16	7.53
percent tardy	41.3	26.5	22.3	19.6	18.6	19.8	22.5	25.2	26.4	26.0
mean lateness	-3.1	-16.2	-18.4	-20.3	-20.3	-19.4	-17.8	-15.7	-14.3	-14.3
absolute deviation	32.46	29.63	29.39	28.25	27.18	25.97	26.88	28.06	28.65	29.41
time in system	67.09	59.15	57.93	56.40	55.89	55.74	56.98	58.67	59.64	60.02
time in shop	16.27	18.12	19.96	21.39	24.14	26.68	28.57	30.62	32.68	35.89
time in pool	33.00	18.08	14.03	10.68	7.97	6.34	6.02	6.16	5.47	2.25
M/H time	1.82	1.86	1.88	1.90	1.93	1.95	1.96	1.97	1.97	1.97
time in IQ	5.51	5.80	5.95	6.11	6.29	6.48	6.48	6.56	6.59	6.60
blocking time	0.18	0.21	0.24	0.27	0.30	0.32	0.33	0.34	0.34	0.35
time in OQ	5.26	6.74	8.36	9.60	12.10	14.41	16.28	18.24	20.26	23.45
time in FGI	17.82	22.94	23.93	24.32	23.76	22.71	22.38	21.88	21.48	21.87
jobs in shop	23.73	26.39	29.04	31.14	35.12	38.80	41.49	44.45	47.39	52.08
std. of flowtime	15.27	15.46	16.85	17.93	20.01	21.76	23.19	24.79	26.85	28.73
std. of jobs in shop	1.86	3.73	4.85	5.89	7.43	8.17	8.47	8.81	9.80	10.67

Table A.7: Simulation results of Aggregate Loading(cont.) with MOD dispatching rule under high machine,transporter utilization, and tight due dates.

Number of jobs allowed	12	14	16	18	20	25	30
mean flowtime	12.14	10.54	10.13	9.98	9.92	9.91	9.92
mean tardiness	0.71	0.24	0.14	0.12	0.10	0.09	0.09
percent tardy	15.1	8.53	6.53	5.83	5.42	5.28	5.24
mean lateness	-10.58	-12.18	-12.59	-12.75	-12.80	-12.82	-12.81
absolute deviation	12.00	12.68	12.89	12.99	13.01	13.00	12.99
time in system	23.44	22.98	22.88	22.85	22.84	22.82	22.82
time in shop	8.74	9.00	9.19	9.28	9.34	9.40	9.43
time in pool	3.40	1.54	0.94	0.69	0.58	0.50	0.48
M/H time	1.59	1.60	1.61	1.61	1.61	1.62	1.62
time in IQ	2.67	2.79	2.87	2.90	2.93	2.95	2.96
blocking time	0.02	0.03	0.03	0.04	0.04	0.04	0.04
time in OQ	0.94	1.07	1.16	1.22	1.24	1.28	1.30
time in FGI	11.29	12.43	12.74	12.87	12.91	12.91	12.90
jobs in shop	10.23	10.51	10.72	10.82	10.88	10.96	10.99
std. of flowtime	6.72	6.08	5.99	5.99	6.00	6.01	6.07
std. of jobs in shop	2.37	3.14	3.60	3.90	4.05	4.22	4.30

Table A.8: Simulation results of Aggregate Loading(cont.) with SPT dispatching rule under low machine,transporter utilization, and loose due dates.

Number of jobs allowed	12	14	16	18	20	25	30
mean flowtime	12.22	10.61	10.15	10.00	9.90	9.88	9.87
mean tardiness	1.80	0.82	0.58	0.49	0.44	0.42	0.41
percent tardy	35.5	25.3	21.9	20.7	19.5	19.4	19.4
mean lateness	-2.10	-3.71	-4.17	-4.32	-4.43	-4.44	-4.45
absolute deviation	5.70	5.37	5.34	5.32	5.32	5.28	5.28
time in system	16.13	15.15	14.91	14.83	14.78	14.75	14.75
time in shop	8.73	9.00	9.19	9.30	9.32	9.38	9.39
time in pool	3.49	1.60	0.96	0.69	0.57	0.49	0.48
M/H time	1.59	1.60	1.61	1.61	1.61	1.62	1.62
time in IQ	2.67	2.80	2.87	2.91	2.92	2.94	2.94
blocking time	0.02	0.03	0.03	0.04	0.04	0.04	0.04
time in OQ	0.93	1.06	1.16	1.22	1.24	1.28	1.28
time in FGI	3.90	4.54	4.76	4.82	4.87	4.86	4.87
jobs in shop	10.21	10.50	10.71	10.83	10.85	10.92	10.93
std. of flowtime	6.75	6.14	6.04	6.02	5.96	6.01	6.01
std. of jobs in shop	2.37	3.15	3.60	3.87	4.03	4.17	4.22

Table A.9: Simulation results of Aggregate Loading(cont.) with SPT dispatching rule under low machine,transporter utilization, and tight due dates.

Number of jobs allowed	12	14	16	18	20	25	30
mean flowtime	13.79	11.68	10.90	10.68	10.61	10.54	10.57
mean tardiness	1.08	0.39	0.19	0.12	0.10	0.07	0.07
percent tardy	19.0	10.6	7.31	6.06	5.74	5.11	5.13
mean lateness	-8.93	-11.05	-11.83	-12.05	-12.11	-12.18	-12.16
absolute deviation	11.09	11.84	12.22	12.30	12.32	12.34	12.31
time in system	23.81	23.13	22.93	22.86	22.84	22.81	22.81
time in shop	9.10	9.45	9.64	9.83	9.94	10.02	10.07
time in pool	4.69	2.23	1.25	0.84	0.66	0.52	0.50
M/H time	1.60	1.62	1.62	1.63	1.63	1.63	1.64
time in IQ	2.92	3.07	3.13	3.21	3.24	3.26	3.28
blocking time	0.02	0.03	0.04	0.04	0.04	0.05	0.05
time in OQ	1.04	1.21	1.34	1.44	1.52	1.57	1.59
time in FGI	10.01	11.44	12.02	12.17	12.22	12.26	12.23
jobs in shop	10.63	11.01	11.23	11.44	11.56	11.64	11.70
std. of flowtime	7.68	7.03	6.80	6.78	6.80	6.84	6.87
std. of jobs in shop	2.15	3.10	3.68	4.06	4.33	4.61	4.67

Table A.10: Simulation results of Aggregate Loading(cont.) with MOD dispatching rule under low machine,transporter utilization, and loose due dates.

Number of jobs allowed	12	14	16	18	20	25	30
mean flowtime	13.20	11.20	10.69	10.46	10.40	10.35	10.35
mean tardiness	2.17	0.87	0.59	0.45	0.41	0.37	0.37
percent tardy	39.5	27.5	22.9	21.0	20.5	20.4	20.1
mean lateness	-1.12	-3.13	-3.63	-3.87	-3.92	-3.97	-3.97
absolute deviation	5.47	4.88	4.81	4.77	4.75	4.73	4.72
time in system	16.50	15.21	14.92	14.78	14.74	14.71	14.70
time in shop	8.98	9.32	9.55	9.67	9.76	9.84	9.86
time in pool	4.21	1.88	1.14	0.78	0.64	0.50	0.49
M/H time	1.60	1.61	1.62	1.62	1.63	1.63	1.63
time in IQ	2.84	3.00	3.09	3.13	3.15	3.18	3.18
blocking time	0.02	0.03	0.04	0.04	0.04	0.04	0.05
time in OQ	1.00	1.16	1.29	1.36	1.43	1.48	1.49
time in FGI	3.30	4.01	4.22	4.32	4.33	4.35	4.35
jobs in shop	10.49	10.85	11.10	11.24	11.34	11.43	11.45
std. of flowtime	7.21	6.50	6.41	6.37	6.40	6.40	6.42
std. of jobs in shop	2.23	3.11	3.65	4.00	4.25	4.49	4.53

Table A.11: Simulation results of Aggregate Loading(cont.) with MOD dispatching rule under low machine,transporter utilization, and tight due dates.

Number of jobs allowed	18	20	25	30	40	60
mean flowtime	10.47	10.15	9.83	9.78	9.79	9.79
mean tardiness	0.009	0.004	0.005	0.004	0.004	0.004
percent tardy	0.24	0.15	0.05	0.03	0.03	0.03
mean lateness	-104.8	-105.2	-105.5	105.5	-105.5	-105.5
absolute deviation	104.9	105.2	105.5	105.5	105.5	105.5
time in system	115.3	115.3	115.3	115.3	115.3	115.3
time in shop	9.35	9.52	9.71	9.77	9.79	9.79
time in pool	1.12	0.63	0.11	0.01	0.00	0.00
M/H time	0.00	0.00	0.00	0.00	0.00	0.00
time in IQ	5.85	6.02	6.22	6.27	6.29	6.29
blocking time	0.00	0.00	0.00	0.00	0.00	0.00
time in OQ	0.00	0.00	0.00	0.00	0.00	0.00
time in FGI	104.9	105.2	105.5	105.5	105.5	105.5
jobs in shop	13.29	13.53	13.82	13.89	13.93	13.93
std. of flowtime	10.10	10.41	10.88	10.97	11.01	11.01
std. of jobs in shop	3.89	4.29	4.90	5.07	5.14	5.14

Table A.12: Simulation results of Aggregate Loading(cont.) with SPT dispatching rule under high machine,transporter utilization, and loose due dates, for the shop that does not include material handling system and capacitated queues.

Number of jobs allowed	18	20	25	30	40	60
mean flowtime	28.43	16.61	13.60	13.29	13.13	13.16
mean tardiness	1.64	0.112	0.012	0.008	0.009	0.009
percent tardy	7.54	1.63	0.40	0.29	0.23	0.24
mean lateness	-86.8	-98.7	-101.7	-102.0	-102.2	-102.2
absolute deviation	90.18	98.97	101.78	102.09	102.25	102.22
time in system	116.98	115.48	115.38	115.37	115.37	115.37
time in shop	11.32	11.72	12.25	12.48	12.50	12.54
time in pool	17.11	4.88	1.35	0.80	0.63	0.62
M/H time	1.57	1.57	1.57	1.57	1.57	1.57
time in IQ	5.12	5.48	5.96	6.19	6.21	6.23
blocking time	0.0	0.00	0.00	0.00	0.00	0.00
time in OQ	1.13	1.17	1.21	1.22	1.22	1.23
time in FGI	88.54	98.86	101.77	102.08	102.24	102.21
jobs in shop	16.76	17.33	18.06	18.39	18.42	18.47
std. of flowtime	10.88	10.26	10.95	11.40	11.46	11.53
std. of jobs in shop	1.89	3.04	4.74	5.39	5.65	5.66

Table A.13: Simulation results of Aggregate Loading(cont.) with SPT dispatching rule under high machine,transporter utilization, and loose due dates for the shop that includes material handling system and uncapacitated queues.

Number of jobs allowed	18	20	25	30	40	60
mean flowtime	28.43	16.61	13.60	13.29	13.13	13.16
mean tardiness	1.64	0.112	0.012	0.008	0.009	0.009
percent tardy	7.54	1.63	0.40	0.29	0.23	0.24
mean lateness	-86.8	-98.7	-101.7	-102.0	-102.2	-102.2
absolute deviation	90.18	98.97	101.78	102.09	102.25	102.22
time in system	116.98	115.48	115.38	115.37	115.37	115.37
time in shop	11.32	11.72	12.25	12.48	12.50	12.54
time in pool	17.11	4.88	1.35	0.80	0.63	0.62
M/H time	1.57	1.57	1.57	1.57	1.57	1.57
time in IQ	5.12	5.48	5.96	6.19	6.21	6.23
blocking time	0.0	0.00	0.00	0.00	0.00	0.00
time in OQ	1.13	1.17	1.21	1.22	1.22	1.23
time in FGI	88.54	98.86	101.77	102.08	102.24	102.21
jobs in shop	16.76	17.33	18.06	18.39	18.42	18.47
std. of flowtime	10.88	10.26	10.95	11.40	11.46	11.53
std. of jobs in shop	1.89	3.04	4.74	5.39	5.65	5.66

Table A.13: Simulation results of Aggregate Loading(cont.) with SPT dispatching rule under high machine,transporter utilization, and loose due dates for the shop that includes material handling system and uncapacitated queues.

Number of jobs allowed	18	20	25	30	40	60
mean flowtime	12.82	11.87	11.08	11.00	10.97	10.93
mean tardiness	0.056	0.026	0.003	0.002	0.0009	0.0008
percent tardy	0.85	0.50	0.15	0.11	0.075	0.09
mean lateness	-102.54	-103.49	-104.28	-104.36	-104.39	-104.43
absolute deviation	102.66	103.55	104.29	104.36	104.39	104.43
time in system	115.42	115.39	115.37	115.37	115.37	115.37
time in shop	10.08	10.32	10.65	10.83	10.96	10.93
time in pool	2.73	1.54	0.42	0.16	0.01	0.00
M/H time	0.00	0.00	0.00	0.00	0.00	0.00
time in IQ	4.94	5.00	5.05	5.08	5.10	5.09
blocking time	0.00	0.00	0.00	0.00	0.00	0.00
time in OQ	1.64	1.82	2.10	2.25	2.36	2.34
time in FGI	102.60	103.52	104.28	104.36	104.39	104.43
jobs in shop	14.33	14.68	15.15	15.42	15.61	15.56
std. of flowtime	9.54	9.65	9.76	9.86	10.02	9.99
std. of jobs in shop	3.63	4.32	5.35	5.81	6.11	6.12

Table A.14: Simulation results of Aggregate Loading(cont.) with SPT dispatching rule under high machine,transporter utilization, and loose due dates, for the shop that does not include material handling system and includes capacitated queues.

Number of jobs allowed	50	60	70	80	90	100	120	150
mean flowtime	65.99	60.78	60.20	64.64	62.47	64.82	62.77	68.75
mean tardiness	8.62	6.23	5.59	6.20	5.89	6.88	6.43	9.39
percent tardy	23.8	19.5	18.6	20.2	18.5	19.9	17.7	18.6
mean lateness	-49.3	-54.5	-55.1	-50.7	-52.9	-50.5	-52.5	-46.6
absolute deviation	66.61	67.04	66.35	63.14	64.71	64.31	65.45	65.47
time in system	123.9	121.6	120.9	121.5	121.2	122.2	121.7	124.8
time in shop	27.28	31.23	34.73	39.38	41.84	44.73	48.40	57.68
time in pool	38.71	29.55	25.46	25.25	20.63	20.09	14.37	11.07
M/H time	2.01	2.05	2.06	2.09	2.08	2.08	2.08	2.11
time in IQ	7.10	7.38	7.40	7.62	7.54	7.58	7.59	7.79
blocking time	0.44	0.48	0.49	0.52	0.50	0.52	0.52	0.55
time in OQ	14.22	17.81	21.26	25.64	28.20	31.03	34.69	43.71
time in FGI	57.98	60.81	60.76	56.94	58.82	57.42	59.01	56.07
jobs in shop	39.41	45.06	50.06	56.73	60.25	64.35	69.87	82.94
std. of flowtime	20.44	23.37	26.83	31.11	35.33	37.88	42.09	52.61
std. of jobs in shop	4.97	6.52	7.36	7.91	8.78	9.67	11.04	12.16

Table A.15: Simulation results of Aggregate Loading(per.) with SPT dispatching rule under high machine,transporter utilization, and loose due dates.

Number of jobs allowed	50	60	70	80	90	100	120	150
mean flowtime	65.37	61.26	62.60	64.76	66.37	65.97	65.67	68.85
mean tardiness	24.33	20.55	21.26	23.41	25.50	25.02	24.67	28.21
percent tardy	56.4	53.7	54.6	54.9	54.8	53.7	51.8	50.4
mean lateness	12.93	8.81	10.14	12.28	13.93	13.53	13.21	16.41
absolute deviation	35.74	32.28	32.39	34.54	37.06	36.51	36.13	40.00
time in system	76.77	72.99	73.72	75.89	77.93	77.46	77.13	80.64
time in shop	27.14	31.29	35.64	39.01	41.62	44.38	50.01	57.03
time in pool	38.23	29.96	26.95	25.75	24.75	21.59	15.65	11.81
M/H time	2.01	2.05	2.07	2.08	2.08	2.09	2.09	2.10
time in IQ	7.06	7.34	7.53	7.58	7.55	7.61	7.64	7.68
blocking time	0.44	0.48	0.51	0.51	0.51	0.52	0.53	0.53
time in OQ	14.12	17.92	22.03	25.32	27.97	30.65	36.24	43.21
time in FGI	11.40	11.73	11.12	11.13	11.56	11.49	11.45	11.79
jobs in shop	39.15	45.11	51.31	56.12	59.88	63.81	10.97	82.02
std. of flowtime	19.92	23.44	27.93	31.05	33.76	36.67	44.14	54.44
std. of jobs in shop	5.04	6.40	7.28	8.02	8.24	9.11	10.97	12.47

Table A.16: Simulation results of Aggregate Loading(per.) with SPT dispatching rule under high machine,transporter utilization, and tight due dates.

Number of jobs allowed	50	60	70	80	90	100	120	150
mean flowtime	70.04	64.48	59.87	60.90	68.22	63.82	63.38	68.54
mean tardiness	8.76	5.70	3.68	3.70	4.54	3.39	3.06	4.67
percent tardy	24.5	19.1	15.1	15.6	19.2	16.4	16.2	20.3
mean lateness	-45.3	-50.8	-55.5	-54.4	-47.1	-51.5	-52.0	-46.8
absolute deviation	62.84	62.30	62.89	61.91	56.26	58.31	58.13	56.19
time in system	124.1	121.0	119.0	119.1	119.9	118.7	118.4	120.0
time in shop	27.79	32.44	35.33	38.14	44.38	45.37	49.21	57.52
time in pool	42.25	32.04	24.53	22.75	23.84	18.45	14.17	11.02
M/H time	2.00	2.04	2.05	2.06	2.09	2.08	2.08	2.10
time in IQ	7.02	7.28	7.33	7.41	7.62	7.51	7.54	7.65
blocking time	0.42	0.46	0.47	0.48	0.52	0.50	0.50	0.52
time in OQ	14.83	19.14	21.96	24.68	30.64	31.76	35.58	43.75
time in FGI	54.07	56.59	59.20	58.20	51.71	54.92	55.07	51.52
jobs in shop	40.07	46.75	50.89	54.99	63.81	65.30	70.91	82.77
std. of flowtime	23.20	27.29	30.06	32.71	37.55	38.21	40.22	45.68
std. of jobs in shop	4.83	6.21	7.85	8.99	9.11	10.43	11.96	13.37

Table A.17: Simulation results of Aggregate Loading(per.) with MOD dispatching rule under high machine,transporter utilization, and loose due dates.

Number of jobs allowed	50	60	70	80	90	100	120	150
mean flowtime	61.38	58.52	59.96	61.83	62.44	67.89	66.94	71.49
mean tardiness	20.31	17.27	18.52	19.69	20.76	24.28	24.60	28.24
percent tardy	53.2	51.6	52.6	54.7	53.6	60.0	56.2	58.5
mean lateness	8.92	6.07	7.50	9.37	10.01	15.43	14.50	19.06
absolute deviation	31.69	28.47	29.53	30.02	31.51	33.13	34.69	37.42
time in system	72.77	69.72	70.97	72.16	73.19	76.74	77.04	80.67
time in shop	26.90	31.22	34.77	38.66	41.18	47.08	50.41	58.93
time in pool	34.48	27.29	25.18	23.16	21.26	20.81	16.53	12.56
M/H time	1.99	2.04	2.05	2.07	2.07	2.09	2.09	2.10
time in IQ	6.98	7.29	7.34	7.50	7.50	7.62	7.58	7.72
blocking time	0.42	0.47	0.48	0.50	0.50	0.53	0.52	0.54
time in OQ	14.00	17.91	21.39	25.08	27.59	33.33	36.71	45.06
time in FGI	11.38	11.20	11.01	10.32	10.75	8.84	10.09	9.18
jobs in shop	38.79	45.00	50.09	55.66	59.27	67.62	72.43	84.60
std. of flowtime	20.14	23.45	26.58	29.39	32.50	38.12	41.25	50.14
std. of jobs in shop	5.28	6.84	7.82	8.32	9.06	9.27	10.43	11.73

Table A.18: Simulation results of Aggregate Loading(per.) with MOD dispatching rule under high machine,transporter utilization, and tight due dates.

Number of jobs allowed	20	22	25	30	35
mean flowtime	18.91	17.30	16.77	16.60	16.51
mean tardiness	2.75	1.81	1.52	1.42	1.37
percent tardy	39.3	34.0	32.0	31.2	31.3
mean lateness	-3.82	-5.43	-5.96	-6.13	-6.22
absolute deviation	9.33	9.05	9.01	8.97	8.96
time in system	25.48	24.54	24.26	24.15	24.11
time in shop	10.64	10.83	11.12	11.35	11.38
time in pool	8.26	6.46	5.65	5.24	5.13
M/H time	1.64	1.65	1.66	1.67	1.67
time in IQ	3.60	3.67	3.77	3.80	3.81
blocking time	0.09	0.10	0.11	0.11	0.12
time in OQ	1.79	1.90	2.07	2.25	2.27
time in FGI	6.57	7.24	7.48	7.55	7.59
jobs in shop	12.38	12.60	12.91	13.17	13.21
std. of flowtime	7.90	7.30	7.18	7.25	7.16
std. of jobs in shop	3.96	4.43	4.94	5.44	5.52

Table A.19: Simulation results of Aggregate Loading(per.) with SPT dispatching rule under low machine,transporter utilization, and loose due dates.

Number of jobs allowed	20	22	25	30	35
mean flowtime	18.73	17.29	16.71	16.46	16.44
mean tardiness	5.71	4.48	3.94	3.74	3.73
percent tardy	72.5	69.0	67.8	66.7	66.8
mean lateness	4.40	2.96	2.38	2.13	2.11
absolute deviation	7.03	6.00	5.50	5.35	5.35
time in system	20.05	18.81	18.27	18.07	18.06
time in shop	10.66	10.81	11.08	11.24	11.27
time in pool	8.07	6.48	5.63	5.21	5.16
M/H time	1.64	1.65	1.66	1.66	1.66
time in IQ	3.61	3.66	3.75	3.77	3.76
blocking time	0.09	0.10	0.11	0.11	0.12
time in OQ	1.80	1.89	2.05	2.19	2.22
time in FGI	1.31	1.52	1.56	1.61	1.62
jobs in shop	12.39	12.56	12.86	13.05	13.08
std. of flowtime	7.70	7.31	7.12	7.18	7.15
std. of jobs in shop	3.96	4.42	4.91	5.37	5.49

Table A.20: Simulation results of Aggregate Loading(per.) with SPT dispatching rule under low machine,transporter utilization, and tight due dates.

Number of jobs allowed	20	22	25	30	35
mean flowtime	18.73	17.35	16.80	16.60	16.63
mean tardiness	2.60	1.83	1.50	1.36	1.34
percent tardy	39.4	34.3	32.5	31.2	31.6
mean lateness	-3.99	-5.37	-5.92	-6.13	-6.08
absolute deviation	9.20	9.04	8.93	8.85	8.78
time in system	25.33	24.56	24.23	24.09	24.07
time in shop	10.62	10.84	11.12	11.33	11.49
time in pool	8.10	6.51	5.67	5.27	5.14
M/H time	1.64	1.65	1.66	1.66	1.67
time in IQ	3.60	3.66	3.74	3.80	3.83
blocking time	0.09	0.10	0.11	0.11	0.11
time in OQ	1.78	1.92	2.11	2.24	2.36
time in FGI	6.60	7.20	7.43	7.49	7.43
jobs in shop	12.35	12.60	12.92	13.15	13.34
std. of flowtime	7.86	7.39	7.27	7.31	7.38
std. of jobs in shop	3.95	4.41	4.92	5.41	5.61

Table A.21: Simulation results of Aggregate Loading(per.) with MOD dispatching rule under low machine,transporter utilization, and loose due dates.

Number of jobs allowed	20	22	25	30	35
mean flowtime	18.73	17.35	16.80	16.60	16.63
mean tardiness	2.60	1.83	1.50	1.36	1.34
percent tardy	39.4	34.3	32.5	31.2	31.6
mean lateness	-3.99	-5.37	-5.92	-6.13	-6.08
absolute deviation	9.20	9.04	8.93	8.85	8.78
time in system	25.33	24.56	24.23	24.09	24.07
time in shop	10.62	10.84	11.12	11.33	11.49
time in pool	8.10	6.51	5.67	5.27	5.14
M/H time	1.64	1.65	1.66	1.66	1.67
time in IQ	3.60	3.66	3.74	3.80	3.83
blocking time	0.09	0.10	0.11	0.11	0.11
time in OQ	1.78	1.92	2.11	2.24	2.36
time in FGI	6.60	7.20	7.43	7.49	7.43
jobs in shop	12.35	12.60	12.92	13.15	13.34
std. of flowtime	7.86	7.39	7.27	7.31	7.38
std. of jobs in shop	3.95	4.41	4.92	5.41	5.61

Table A.21: Simulation results of Aggregate Loading(per.) with MOD dispatching rule under low machine,transporter utilization, and loose due dates.

Number of jobs allowed	20	22	25	30	35
mean flowtime	18.70	17.26	16.65	16.51	16.47
mean tardiness	5.69	4.43	3.87	3.75	3.72
percent tardy	72.4	68.9	67.7	67.2	67.3
mean lateness	4.37	2.93	2.32	2.18	2.14
absolute deviation	7.01	5.93	5.43	5.31	5.31
time in system	20.02	18.76	18.21	18.08	18.05
time in shop	10.63	10.83	11.05	11.27	11.29
time in pool	8.07	6.42	5.60	5.24	5.17
M/H time	1.64	1.65	1.66	1.66	1.66
time in IQ	3.60	3.66	3.72	3.79	3.78
blocking time	0.09	0.10	0.11	0.11	0.11
time in OQ	1.79	1.92	2.05	2.19	2.23
time in FGI	1.31	1.50	1.55	1.56	1.58
jobs in shop	12.36	12.58	12.83	13.08	13.10
std. of flowtime	7.80	7.30	7.15	7.16	7.17
std. of jobs in shop	3.96	4.41	4.93	5.33	5.51

Table A.22: Simulation results of Aggregate Loading(per.) with MOD dispatching rule under low machine,transporter utilization, and tight due dates.

Load level	1.1	1.25	1.5	2	3	4	5	6
mean flowtime	34.88	31.72	28.69	25.41	24.94	26.58	31.33	38.51
mean tardiness	3.81	2.80	2.18	1.48	1.26	1.76	3.54	6.81
percent tardy	10.7	9.15	7.61	5.91	5.27	5.84	7.74	10.7
mean lateness	-80.4	-83.6	-86.6	-89.9	-90.4	-88.7	-84.0	-76.8
absolute deviation	88.13	89.26	91.06	92.97	93.00	92.32	91.11	90.46
time in system	119.2	118.1	117.5	116.8	116.6	117.1	118.9	122.1
time in shop	11.14	11.34	11.33	11.72	13.03	14.17	15.78	17.46
time in pool	23.74	20.38	17.35	13.68	11.90	12.41	15.54	21.04
M/H time	1.64	1.64	1.64	1.66	1.71	1.76	1.82	1.88
time in IQ	3.87	3.98	4.02	4.26	4.96	5.43	5.81	6.13
blocking time	0.17	0.17	0.17	0.18	0.20	0.23	0.27	0.32
time in OQ	1.95	2.03	1.99	2.11	2.65	3.24	4.37	5.62
time in FGI	84.31	86.45	88.87	91.48	91.73	90.55	87.56	83.64
jobs in shop	16.51	16.80	16.79	17.34	19.21	20.83	23.15	25.51
std. of flowtime	25.63	22.85	21.30	19.06	18.25	19.93	23.98	31.19
std. of jobs in shop	3.16	3.36	3.43	3.67	4.14	4.39	4.84	5.16

Table A.23: Simulation results of Workcenter Information Based Loading(cont.) with SPT dispatching rule under high machine,transporter utilization, and loose due dates.

Load level	1.1	1.25	1.5	2	3	4	5	6
mean flowtime	35.64	32.03	29.02	25.97	25.36	27.91	32.73	40.35
mean tardiness	9.42	7.36	5.68	4.18	3.97	5.69	8.86	14.25
percent tardy	26.9	23.6	20.6	17.4	15.5	16.5	19.1	22.9
mean lateness	-16.8	-20.4	-23.4	-26.4	-27.0	-24.5	-19.7	-12.1
absolute deviation	35.68	35.15	34.78	34.82	35.04	35.95	37.46	40.63
time in system	61.90	59.83	58.12	56.61	56.42	58.17	61.33	66.73
time in shop	11.14	11.22	11.31	11.76	13.02	14.34	15.88	17.82
time in pool	24.50	20.81	17.70	14.20	12.34	13.56	16.85	22.52
M/H time	1.63	1.64	1.64	1.66	1.71	1.76	1.83	1.89
time in IQ	3.88	3.92	4.01	4.29	4.95	5.46	5.86	6.22
blocking time	0.17	0.17	0.17	0.18	0.20	0.24	0.28	0.33
time in OQ	1.93	1.97	1.97	2.13	2.64	3.37	4.40	5.87
time in FGI	26.25	27.79	29.10	30.64	31.06	30.25	28.60	26.37
jobs in shop	16.50	16.61	16.75	17.40	19.20	21.07	23.24	26.00
std. of flowtime	25.35	23.87	21.63	19.11	18.70	21.43	26.09	33.26
std. of jobs in shop	3.21	3.31	3.33	3.69	4.13	4.50	4.89	5.37

Table A.24: Simulation results of Workcenter Information Based Loading(cont.) with SPT dispatching rule under high machine,transporter utilization, and tight due dates.

Load level	1.1	1.25	1.5	2	3	4	5	6
mean flowtime	35.19	31.59	29.03	27.43	28.60	35.68	41.77	51.92
mean tardiness	3.38	2.47	1.91	1.60	1.77	4.13	5.94	10.16
percent tardy	10.3	8.46	7.22	6.07	6.19	8.61	10.82	14.10
mean lateness	-80.2	-83.8	-86.3	-87.9	-86.7	-79.6	-73.6	-63.4
absolute deviation	86.98	88.77	90.22	91.16	90.31	87.96	85.49	83.78
time in system	118.7	117.8	117.3	116.9	117.1	119.5	121.3	125.5
time in shop	12.16	12.13	12.39	13.10	14.97	17.30	19.62	22.53
time in pool	23.03	19.45	16.64	14.32	13.63	18.37	22.15	29.39
M/H time	1.66	1.66	1.67	1.70	1.78	1.87	1.94	2.00
time in IQ	4.36	4.37	4.53	4.90	5.63	6.19	6.54	6.90
blocking time	0.18	0.18	0.18	0.19	0.23	0.30	0.35	0.41
time in OQ	2.44	2.40	2.49	2.79	3.81	5.42	7.29	9.71
time in FGI	83.59	86.30	88.30	89.56	88.54	83.82	79.55	73.62
jobs in shop	17.97	17.92	18.30	19.32	21.98	25.30	28.61	32.72
std. of flowtime	24.56	22.26	20.60	19.86	20.89	27.13	30.78	40.10
std. of jobs in shop	3.52	3.57	3.69	4.04	4.58	5.06	5.65	6.24

Table A.25: Simulation results of Workcenter Information Based Loading(cont.) with MOD dispatching rule under high machine,transporter utilization, and loose due dates.

Load level	1.1	1.25	1.5	2	3	4	5	6
mean flowtime	34.26	31.35	28.89	26.53	29.35	35.83	42.79	47.02
mean tardiness	7.82	6.12	5.09	3.69	5.28	9.18	13.64	16.04
percent tardy	24.5	21.8	19.0	16.4	16.9	20.4	24.3	27.3
mean lateness	-18.2	-21.1	-23.5	-25.8	-23.1	-16.6	-9.6	-5.4
absolute deviation	33.86	33.36	33.75	33.28	33.67	34.99	36.97	37.53
time in system	60.30	58.58	57.55	56.13	57.75	61.64	66.11	68.51
time in shop	12.05	12.07	12.23	12.88	14.73	16.99	19.20	21.21
time in pool	22.20	19.28	16.65	13.65	14.62	18.84	23.58	25.81
M/H time	1.66	1.66	1.67	1.69	1.77	1.86	1.93	1.98
time in IQ	4.30	4.35	4.46	4.84	5.57	6.13	6.50	6.72
blocking time	0.18	0.17	0.18	0.19	0.23	0.29	0.34	0.38
time in OQ	2.40	2.37	2.42	2.65	3.65	5.19	6.91	8.62
time in FGI	26.04	27.23	28.65	29.59	28.39	25.81	23.32	21.49
jobs in shop	17.81	17.83	18.08	19.01	21.62	24.83	27.95	30.80
std. of flowtime	24.19	21.80	20.29	18.51	21.20	26.79	32.29	35.34
std. of jobs in shop	3.45	3.52	3.62	4.02	4.44	5.08	5.46	5.71

Table A.26: Simulation results of Workcenter Information Based Loading(cont.) with MOD dispatching rule under high machine,transporter utilization, and tight due dates.

Load level	0.5	2	4	6	8	16
mean flowtime	12.68	10.73	10.21	10.03	9.95	9.92
mean tardiness	1.07	0.44	0.24	0.14	0.11	0.09
percent tardy	17.3	10.1	7.15	5.88	5.50	5.21
mean lateness	-10.0	-12.0	-12.5	-12.6	-12.7	-12.8
absolute deviation	12.20	12.89	13.01	12.98	13.01	12.99
time in system	23.80	23.18	22.98	22.88	22.85	22.82
time in shop	8.20	8.49	9.08	9.31	9.38	9.43
time in pool	4.47	2.23	1.12	0.72	0.57	0.48
M/H time	1.58	1.58	1.60	1.61	1.62	1.62
time in IQ	2.14	2.41	2.86	2.97	2.95	2.96
blocking time	0.04	0.04	0.04	0.04	0.04	0.04
time in OQ	0.93	0.94	1.07	1.18	1.25	1.30
time in FGI	11.12	12.44	12.76	12.84	12.90	12.90
jobs in shop	9.64	9.95	10.60	10.85	10.92	10.99
std. of flowtime	7.55	6.36	6.15	6.13	6.03	6.06
std. of jobs in shop	2.79	3.29	3.77	4.02	4.15	4.29

Table A.27: Simulation results of Workcenter Information Based Loading(cont.) with SPT dispatching rule under low machine,transporter utilization, and loose due dates.

Load level	0.5	2	4	6	8	16
mean flowtime	12.61	10.72	10.13	9.98	9.91	9.88
mean tardiness	2.16	1.04	0.65	0.51	0.44	0.42
percent tardy	36.5	25.4	21.5	20.1	19.4	19.5
mean lateness	-1.71	-3.61	-4.19	-4.34	-4.41	-4.44
absolute deviation	6.03	5.69	5.49	5.36	5.31	5.28
time in system	16.48	15.37	14.98	14.84	14.78	14.75
time in shop	8.20	8.49	9.04	9.27	9.34	9.40
time in pool	4.40	2.23	1.09	0.71	0.57	0.48
M/H time	1.58	1.58	1.60	1.61	1.62	1.62
time in IQ	2.15	2.41	2.84	2.94	2.94	2.94
blocking time	0.04	0.04	0.04	0.04	0.04	0.04
time in OQ	0.93	0.94	1.05	1.17	1.23	1.28
time in FGI	3.87	4.65	4.84	4.85	4.86	4.86
jobs in shop	9.64	9.94	10.54	10.79	10.87	10.93
std. of flowtime	7.55	6.40	6.06	6.08	6.01	6.03
std. of jobs in shop	2.79	3.28	3.72	3.99	4.10	4.22

Table A.28: Simulation results of Workcenter Information Based Loading(cont.) with SPT dispatching rule under low machine,transporter utilization, and tight due dates.

Load level	0.5	2	4	6	8	16
mean flowtime	13.01	11.04	10.77	10.64	10.60	10.53
mean tardiness	1.06	0.39	0.21	0.12	0.10	0.07
percent tardy	17.0	9.68	6.92	5.58	5.37	5.14
mean lateness	-9.71	-11.68	-11.96	-12.09	-12.13	-12.20
absolute deviation	11.84	12.48	12.40	12.34	12.35	12.35
time in system	23.79	23.13	22.95	22.86	22.84	22.81
time in shop	8.48	8.83	9.61	9.91	10.00	10.03
time in pool	4.52	2.20	1.15	0.73	0.59	0.49
M/H time	1.58	1.59	1.62	1.63	1.64	1.63
time in IQ	2.36	2.67	3.18	3.27	3.26	3.26
blocking time	0.04	0.04	0.05	0.05	0.05	0.05
time in OQ	0.99	1.02	1.26	1.44	1.54	1.58
time in FGI	10.78	12.08	12.18	12.21	12.24	12.28
jobs in shop	9.95	10.33	11.19	11.52	11.62	11.66
std. of flowtime	7.72	6.67	6.83	6.88	6.89	6.82
std. of jobs in shop	2.93	3.46	4.10	4.41	4.54	4.66

Table A.29: Simulation results of Workcenter Information Based Loading(cont.) with MOD dispatching rule under low machine,transporter utilization, and loose due dates.

Load level	0.5	2	4	6	8	16
mean flowtime	13.01	11.04	10.77	10.64	10.60	10.53
mean tardiness	1.06	0.39	0.21	0.12	0.10	0.07
percent tardy	17.0	9.68	6.92	5.58	5.37	5.14
mean lateness	-9.71	-11.68	-11.96	-12.09	-12.13	-12.20
absolute deviation	11.84	12.48	12.40	12.34	12.35	12.35
time in system	23.79	23.13	22.95	22.86	22.84	22.81
time in shop	8.48	8.83	9.61	9.91	10.00	10.03
time in pool	4.52	2.20	1.15	0.73	0.59	0.49
M/H time	1.58	1.59	1.62	1.63	1.64	1.63
time in IQ	2.36	2.67	3.18	3.27	3.26	3.26
blocking time	0.04	0.04	0.05	0.05	0.05	0.05
time in OQ	0.99	1.02	1.26	1.44	1.54	1.58
time in FGI	10.78	12.08	12.18	12.21	12.24	12.28
jobs in shop	9.95	10.33	11.19	11.52	11.62	11.66
std. of flowtime	7.72	6.67	6.83	6.88	6.89	6.82
std. of jobs in shop	2.93	3.46	4.10	4.41	4.54	4.66

Table A.29: Simulation results of Workcenter Information Based Loading(cont.) with MOD dispatching rule under low machine,transporter utilization, and loose due dates.

Load level	0.5	2	4	6	8	16
mean flowtime	12.96	11.00	10.59	10.48	10.43	10.36
mean tardiness	2.18	0.96	0.59	0.46	0.42	0.37
percent tardy	37.4	25.0	21.4	20.7	20.5	20.2
mean lateness	-1.36	-3.32	-3.73	-3.85	-3.89	-3.97
absolute deviation	5.72	5.25	4.92	4.77	4.74	4.71
time in system	16.51	15.30	14.92	14.79	14.75	14.70
time in shop	8.45	8.78	9.45	9.74	9.84	9.86
time in pool	4.51	2.22	1.14	0.73	0.58	0.49
M/H time	1.58	1.59	1.61	1.63	1.63	1.63
time in IQ	2.34	2.63	3.09	3.19	3.20	3.19
blocking time	0.04	0.05	0.04	0.04	0.05	0.05
time in OQ	0.98	1.00	1.19	1.37	1.45	1.49
time in FGI	3.54	4.29	4.32	4.31	4.32	4.34
jobs in shop	9.90	10.26	10.99	11.32	11.43	11.45
std. of flowtime	7.62	6.56	6.44	6.44	6.45	6.41
std. of jobs in shop	2.89	3.42	3.94	4.29	4.42	4.52

Table A.30: Simulation results of Workcenter Information Based Loading(cont.) with MOD dispatching rule under low machine,transporter utilization, and tight due dates.

Machine and transporter utilizations	Low				High			
Due Date Tightness	Loose		Tight		Loose		Tight	
Dispatching Rule	SPT	MOD	SPT	MOD	SPT	MOD	SPT	MOD
mean flowtime	23.15	23.23	15.26	15.13	179.6	172.5	100.0	97.65
mean tardiness	1.77	1.60	1.92	1.61	79.9	60.26	52.18	46.54
percent tardy	47.0	52.3	55.0	58.1	53.9	78.1	61.8	82.1
mean lateness	0.41	0.49	0.93	0.79	64.16	56.99	47.65	45.21
absolute deviation	3.14	2.71	2.91	2.43	95.7	63.53	56.71	47.87
time in system	24.5	24.3	16.2	15.9	195.4	175.7	104.6	98.98
time in shop	9.97	10.57	10.01	10.20	154.2	145.6	89.60	86.68
time in pool	13.18	12.66	5.25	4.92	25.45	26.83	10.48	10.97
M/H time	1.64	1.65	1.64	1.64	2.16	2.17	2.13	2.12
time in IQ	3.14	3.41	3.18	3.32	7.87	7.99	7.69	7.60
blocking time	0.05	0.06	0.05	0.05	0.56	0.56	0.53	0.50
time in OQ	1.63	1.93	1.63	1.67	140.1	131.4	75.74	72.95
time in FGI	1.36	1.10	0.99	0.81	15.80	3.27	4.53	1.32
jobs in shop	11.59	12.26	11.63	11.83	219.1	207.5	128.3	124.3
std. of flowtime	15.76	15.23	10.56	9.98	173.0	135.2	94.57	82.53
std. of jobs in shop	5.30	5.88	5.39	5.18	26.58	30.29	27.86	26.58

Table A.31: Simulation results of Infinite Loading(cont.)

Machine and transporter utilizations	Low				High			
Due Date Tightness	Loose		Tight		Loose		Tight	
Dispatching Rule	SPT	MOD	SPT	MOD	SPT	MOD	SPT	MOD
mean flowtime	24.43	24.36	18.23	17.99	220.7	198.3	118.9	111.3
mean tardiness	3.10	3.06	4.56	4.41	121.7	85.28	68.96	59.57
percent tardy	58.3	59.1	76.3	74.7	55.1	87.1	77.4	92.3
mean lateness	1.69	1.63	3.90	3.66	105.4	83.00	66.60	58.96
absolute deviation	4.50	4.50	5.23	5.16	137.9	87.55	71.32	60.18
time in system	25.83	25.80	18.90	18.74	237.0	200.6	121.3	111.9
time in shop	12.36	12.52	11.75	11.71	207.1	182.5	109.9	102.1
time in pool	12.07	11.83	6.48	6.28	13.65	15.81	9.05	9.22
M/H time	1.70	1.70	1.68	1.68	2.23	2.22	2.21	2.19
time in IQ	4.10	4.11	3.92	3.91	8.58	8.51	8.44	8.32
blocking time	0.13	0.13	0.12	0.11	0.67	0.65	0.64	0.63
time in OQ	2.92	3.07	2.52	2.49	192.1	167.6	95.12	87.5
time in FGI	1.40	1.43	0.66	0.74	16.28	2.27	2.35	0.60
jobs in shop	14.30	14.48	13.62	13.57	294.2	259.9	156.8	145.8
std. of flowtime	14.40	14.25	9.05	8.82	220.7	170.6	114.3	93.39
std. of jobs in shop	7.16	7.34	6.12	6.06	24.08	23.13	20.20	18.79

Table A.32: Simulation results of Infinite Loading(per.)

Machine and transporter utilizations	Low				High			
Due Date Tightness	Loose		Tight		Loose		Tight	
Dispatching Rule	SPT	MOD	SPT	MOD	SPT	MOD	SPT	MOD
mean flowtime	24.17	23.72	17.42	17.31	174.6	164.6	80.36	68.79
mean tardiness	3.34	3.09	4.24	4.16	67.60	54.74	37.51	26.76
percent tardy	58.8	57.6	71.7	71.5	57.8	72.1	52.2	54.8
mean lateness	1.43	0.99	3.09	2.98	59.16	49.22	27.93	16.36
absolute deviation	5.25	5.19	5.39	5.34	76.04	60.27	47.08	37.16
time in system	26.08	25.82	18.57	18.49	183.0	170.1	89.93	79.19
time in shop	12.76	12.70	11.68	11.65	118.8	116.5	72.51	62.74
time in pool	11.40	11.02	5.74	5.65	55.74	48.01	7.84	6.05
M/H time	1.71	1.71	1.68	1.67	2.20	2.18	2.11	2.09
time in IQ	4.24	4.21	3.91	3.91	8.41	8.24	7.78	7.62
blocking time	0.13	0.13	0.12	0.12	0.65	0.62	0.55	0.52
time in OQ	3.17	3.15	2.46	2.44	104.0	102.0	58.56	49.00
time in FGI	1.91	2.09	1.14	1.18	8.43	5.52	9.57	10.39
jobs in shop	14.75	14.68	13.54	13.50	169.3	166.5	103.9	90.09
std. of flowtime	13.08	12.62	7.91	7.79	145.9	126.7	71.51	53.53
std. of jobs in shop	7.27	7.22	5.89	5.88	24.82	25.46	15.73	14.72

Table A.33: Simulation results of Forward Finite Loading

WIP limit	9	10	11	12	13	14
mean flowtime	174.11	138.59	133.07	137.82	142.51	151.19
mean tardiness	59.39	24.14	18.87	23.81	28.69	37.61
percent tardy	75.4	69.9	66.7	67.7	67.8	69.2
mean lateness	58.69	23.14	17.62	22.37	27.01	35.71
absolute deviation	60.08	25.13	20.13	25.26	30.36	39.51
time in system	174.81	139.59	134.33	139.27	144.18	153.09
time in shop	11.98	13.34	15.14	18.11	21.85	25.96
time in pool	162.13	125.24	117.92	119.71	120.66	125.22
M/H time	1.67	1.73	1.80	1.90	2.00	2.06
time in IQ	4.48	5.10	5.66	6.36	6.93	7.33
blocking time	0.18	0.19	0.23	0.31	0.38	0.45
time in OQ	2.14	2.81	3.94	6.03	9.02	12.61
time in FGI	0.69	0.99	1.25	1.44	1.67	1.89
jobs in shop	17.60	19.62	22.19	26.47	31.75	37.55
std. of flowtime	114.89	81.37	78.26	81.69	84.44	90.85
std. of jobs in shop	3.13	3.76	4.81	6.15	7.30	8.05

Table A.34: Simulation results of the proposed release mechanism with SPT dispatching rule under high machine,transporter utilization, and loose due dates.

WIP limit	9	10	11	12	13	14
mean flowtime	113.67	81.13	72.90	76.08	84.23	92.87
mean tardiness	61.76	29.38	21.34	24.67	32.87	41.58
percent tardy	81.5	77.3	74.9	75.0	77.8	79.7
mean lateness	61.25	28.67	20.43	23.61	31.77	40.45
absolute deviation	62.27	30.10	22.26	25.73	33.96	42.72
time in system	114.18	81.84	73.81	77.14	85.32	94.01
time in shop	12.00	13.59	15.44	18.50	22.39	26.34
time in pool	101.67	67.53	57.46	57.57	61.83	66.53
M/H time	1.67	1.73	1.81	1.91	2.00	2.07
time in IQ	4.50	5.19	5.75	6.46	7.03	7.40
blocking time	0.18	0.21	0.25	0.33	0.41	0.47
time in OQ	2.14	2.94	4.11	6.29	9.44	12.89
time in FGI	0.50	0.71	0.91	1.05	1.09	1.13
jobs in shop	17.66	19.99	22.62	26.96	32.52	38.09
std. of flowtime	89.20	52.22	44.03	45.96	51.56	60.50
std. of jobs in shop	3.20	3.79	4.92	5.89	6.90	7.33

Table A.35: Simulation results of the proposed release mechanism with SPT dispatching rule under high machine,transporter utilization, and tight due dates.

WIP limit	9	10	11	12	13	14
mean flowtime	137.54	128.15	129.40	132.64	138.87	149.34
mean tardiness	24.86	15.99	17.17	20.18	25.93	35.97
percent tardy	51.9	45.8	47.6	51.3	58.4	66.4
mean lateness	22.07	12.75	13.98	17.20	23.42	33.92
absolute deviation	27.66	19.23	20.35	23.17	28.44	38.01
time in system	140.34	131.40	132.58	135.63	141.38	151.38
time in shop	12.57	14.07	16.45	19.36	23.11	27.04
time in pool	124.97	114.08	112.94	113.28	115.76	122.29
M/H time	1.69	1.76	1.85	1.94	2.02	2.08
time in IQ	4.82	5.36	6.06	6.60	7.07	7.42
blocking time	0.19	0.22	0.27	0.33	0.40	0.46
time in OQ	2.36	3.23	4.75	6.97	10.10	13.56
time in FGI	2.79	3.24	3.18	2.98	2.50	2.04
jobs in shop	18.52	20.67	24.07	28.23	33.52	39.10
std. of flowtime	78.36	74.06	75.31	77.39	79.66	89.73
std. of jobs in shop	3.60	4.50	5.60	6.53	7.49	8.59

Table A.36: Simulation results of the proposed release mechanism with MOD dispatching rule under high machine,transporter utilization, and loose due dates.

WIP limit	9	10	11	12	13	14
mean flowtime	108.32	79.08	73.56	77.28	85.01	93.49
mean tardiness	56.44	27.37	22.02	25.72	33.35	41.68
percent tardy	79.8	76.5	74.3	76.9	81.4	85.6
mean lateness	55.87	26.62	21.11	24.81	32.54	41.03
absolute deviation	57.01	28.11	22.93	26.62	34.15	42.34
time in system	108.89	79.83	74.47	78.18	85.82	94.14
time in shop	12.13	13.65	15.74	18.58	22.56	26.76
time in pool	96.18	65.42	57.82	58.69	62.45	66.72
M/H time	1.68	1.74	1.82	1.91	2.01	2.08
time in IQ	4.57	5.22	5.82	6.48	7.03	7.47
blocking time	0.18	0.21	0.26	0.33	0.40	0.47
time in OQ	2.20	2.97	4.32	6.35	9.60	13.23
time in FGI	0.57	0.74	0.91	0.90	0.80	0.65
jobs in shop	17.82	20.07	23.04	27.11	32.76	38.70
std. of flowtime	82.35	50.31	45.00	47.48	52.38	55.77
std. of jobs in shop	3.22	3.99	4.94	5.82	6.93	7.71

Table A.37: Simulation results of the proposed release mechanism with MOD dispatching rule under high machine,transporter utilization, and tight due dates.

WIP limit	10	12	14	16	18	20
mean flowtime	27.11	25.83	25.44	25.23	25.27	25.21
mean tardiness	4.91	3.71	3.36	3.15	3.20	3.15
percent tardy	72.8	70.9	70.4	70.0	70.0	69.8
mean lateness	4.36	3.09	2.70	2.49	2.53	2.47
absolute deviation	5.46	4.33	4.01	3.82	3.88	3.82
time in system	27.65	26.45	26.10	25.89	25.95	25.89
time in shop	9.75	10.59	11.10	11.23	11.43	11.44
time in pool	17.35	15.23	14.34	14.00	13.84	13.76
M/H time	1.62	1.65	1.67	1.67	1.68	1.68
time in IQ	3.22	3.55	3.70	3.69	3.74	3.75
blocking time	0.06	0.07	0.07	0.07	0.07	0.07
time in OQ	1.33	1.81	2.15	2.28	2.42	2.43
time in FGI	0.54	0.62	0.65	0.66	0.67	0.67
jobs in shop	11.35	12.29	12.86	13.00	13.22	13.23
std. of flowtime	14.91	14.46	14.51	14.59	14.70	14.74
std. of jobs in shop	3.88	4.94	5.73	5.92	6.27	6.32

Table A.38: Simulation results of the proposed release mechanism with SPT dispatching rule under low machine,transporter utilization, and loose due dates.

WIP limit	10	12	14	16	18	20
mean flowtime	20.68	19.23	18.96	18.77	18.79	18.73
mean tardiness	6.53	5.13	4.86	4.68	4.70	4.63
percent tardy	87.6	86.0	85.5	85.5	85.4	85.5
mean lateness	6.34	4.91	4.63	4.44	4.46	4.39
absolute deviation	6.72	5.35	5.10	4.91	4.95	4.86
time in system	20.86	19.45	19.20	19.01	19.03	18.96
time in shop	9.85	10.57	11.09	11.15	11.29	11.24
time in pool	10.82	8.66	7.87	7.62	7.50	7.49
M/H time	1.62	1.65	1.67	1.67	1.67	1.67
time in IQ	3.24	3.55	3.69	3.68	3.74	3.72
blocking time	0.08	0.08	0.08	0.08	0.08	0.08
time in OQ	1.40	1.78	2.14	2.21	2.28	2.26
time in FGI	0.18	0.22	0.23	0.23	0.24	0.23
jobs in shop	11.48	12.27	12.85	12.92	13.08	13.02
std. of flowtime	10.18	9.60	9.63	9.58	9.70	9.67
std. of jobs in shop	3.95	4.79	5.41	5.58	5.85	5.79

Table A.39: Simulation results of the proposed release mechanism with SPT dispatching rule under low machine,transporter utilization, and tight due dates.

WIP limit	10	12	14	16	18	20
mean flowtime	26.63	25.53	25.23	25.11	25.01	25.12
mean tardiness	4.52	3.50	3.22	3.11	3.02	3.12
percent tardy	70.3	68.9	68.9	69.1	68.4	68.7
mean lateness	3.90	2.79	2.49	2.36	2.27	2.37
absolute deviation	5.15	4.20	3.95	3.86	3.77	3.87
time in system	27.25	26.23	25.96	25.86	25.76	25.86
time in shop	9.75	10.65	11.14	11.44	11.47	11.65
time in pool	16.87	14.87	14.08	13.67	13.54	13.46
M/H time	1.62	1.66	1.67	1.68	1.68	1.68
time in IQ	3.22	3.58	3.70	3.77	3.75	3.80
blocking time	0.06	0.07	0.07	0.07	0.07	0.07
time in OQ	1.34	1.84	2.19	2.40	2.45	2.58
time in FGI	0.62	0.70	0.73	0.74	0.75	0.74
jobs in shop	11.35	12.35	12.90	13.23	13.26	13.47
std. of flowtime	14.58	14.26	14.38	14.51	14.50	14.62
std. of jobs in shop	3.98	5.03	5.74	6.25	6.32	6.62

Table A.40: Simulation results of the proposed release mechanism with MOD dispatching rule under low machine,transporter utilization, and loose due dates.

WIP limit	10	12	14	16	18	20
mean flowtime	20.06	18.99	18.65	18.47	18.46	18.51
mean tardiness	5.98	4.95	4.61	4.43	4.43	4.47
percent tardy	85.1	83.5	83.2	83.2	83.2	83.6
mean lateness	5.73	4.66	4.32	4.14	4.13	4.18
absolute deviation	6.22	5.24	4.90	4.73	4.73	4.76
time in system	20.31	19.28	18.94	18.76	18.77	18.80
time in shop	9.80	10.58	10.98	11.05	11.19	11.25
time in pool	10.26	8.41	7.67	7.41	7.27	7.26
M/H time	1.62	1.65	1.66	1.66	1.67	1.67
time in IQ	3.23	3.55	3.65	3.65	3.69	3.71
blocking time	0.07	0.08	0.08	0.08	0.08	0.08
time in OQ	1.37	1.78	2.07	2.15	2.24	2.27
time in FGI	0.24	0.28	0.29	0.29	0.30	0.29
jobs in shop	11.41	12.29	12.73	12.82	12.96	13.04
std. of flowtime	9.81	9.41	9.38	9.32	9.43	9.46
std. of jobs in shop	3.91	4.80	5.30	5.45	5.63	5.78

Table A.41: Simulation results of the proposed release mechanism with MOD dispatching rule under low machine,transporter utilization, and tight due dates.

Due Date Tightness	Loose			Tight		
interval length	2	4	6	2	4	6
mean flowtime	31.42	34.65	48.55	32.55	34.69	50.36
mean tardiness	1.91	1.26	2.32	5.66	5.30	12.08
percent tardy	4.66	5.95	11.63	19.61	24.37	44.18
mean lateness	-83.94	-80.72	-66.78	-19.91	-17.77	-2.09
absolute deviation	87.76	83.25	71.44	31.24	28.38	26.26
time in system	117.27	116.64	117.66	58.13	57.77	64.54
time in shop	17.65	15.42	13.34	17.67	15.45	13.47
time in pool	13.76	19.23	35.20	14.87	19.23	36.88
M/H time	1.90	1.82	1.72	1.90	1.82	1.72
time in IQ	6.31	5.88	5.19	6.29	5.87	5.25
blocking time	0.29	0.26	0.25	0.29	0.27	0.26
time in OQ	5.65	3.95	2.68	5.68	3.98	2.73
time in FGI	85.85	81.98	69.11	25.58	23.08	14.17
jobs in shop	25.83	22.63	19.68	25.88	22.68	19.81
std. of flowtime	25.80	22.13	25.49	27.20	22.03	26.80
std. of jobs in shop	4.96	4.15	3.76	4.89	4.37	3.79

Table A.42: Simulation results of the modified PRM for different interval lengths under SPT dispatching rule and high machine and transporter utilization.

Due Date Tightness	Loose			Tight		
interval length	2	4	6	2	4	6
mean flowtime	30.45	30.82	42.17	32.02	34.37	46.11
mean tardiness	1.36	0.81	1.71	4.61	4.66	9.34
percent tardy	4.16	4.56	9.28	18.45	23.72	39.73
mean lateness	-84.92	-84.58	-73.21	-20.45	-18.08	-6.36
absolute deviation	87.64	86.21	76.64	29.68	27.40	25.05
time in system	116.74	116.22	117.11	57.09	57.12	61.82
time in shop	17.64	15.39	14.08	17.93	15.55	13.46
time in pool	12.80	15.43	28.09	14.08	18.82	32.65
M/H time	1.90	1.81	1.75	1.90	1.82	1.72
time in IQ	6.28	5.90	5.49	6.33	5.90	5.23
blocking time	0.28	0.25	0.26	0.29	0.26	0.25
time in OQ	5.67	3.90	3.06	5.89	4.05	2.75
time in FGI	86.28	85.40	74.93	25.07	22.74	15.70
jobs in shop	25.83	22.59	20.72	26.22	22.82	19.82
std. of flowtime	25.20	20.30	22.62	25.38	21.08	24.65
std. of jobs in shop	4.82	4.32	3.79	5.00	4.33	3.76

Table A.43: Simulation results of the modified PRM for different interval lengths under MOD dispatching rule and high machine and transporter utilization.

Due Date Tightness	Loose			Tight		
interval length	2	4	6	2	4	6
mean flowtime	12.32	13.61	15.02	12.23	13.64	15.03
mean tardiness	0.38	0.60	0.91	1.33	1.99	2.79
percent tardy	14.23	19.03	24.82	38.38	49.19	58.38
mean lateness	-10.41	-9.12	-7.71	-2.10	-0.68	0.70
absolute deviation	11.18	10.33	9.53	4.76	4.68	4.88
time in system	23.12	23.33	23.65	15.66	16.33	17.12
time in shop	10.77	10.88	11.06	10.67	10.92	11.05
time in pool	1.55	2.72	3.96	1.55	2.72	3.97
M/H time	1.66	1.66	1.66	1.65	1.66	1.66
time in IQ	3.55	3.62	3.71	3.52	3.62	3.69
blocking time	0.06	0.08	0.10	0.06	0.08	0.10
time in OQ	1.98	2.01	2.07	1.93	2.05	2.10
time in FGI	10.80	9.72	8.62	3.43	2.68	2.08
jobs in shop	12.52	12.66	12.85	12.39	12.69	12.84
std. of flowtime	6.59	6.70	6.89	6.50	6.75	6.97
std. of jobs in shop	5.02	5.07	5.21	4.96	5.12	5.29

Table A.44: Simulation results of the modified PRM for different interval lengths under SPT dispatching rule and low machine and transporter utilization.

Due Date Tightness	Loose			Tight		
interval length	2	4	6	2	4	6
mean flowtime	12.35	13.80	15.18	12.29	13.70	14.96
mean tardiness	0.35	0.60	0.92	1.33	1.99	2.70
percent tardy	13.80	19.37	25.45	39.31	50.07	58.38
mean lateness	-10.37	-8.93	-7.54	-2.04	-0.63	0.63
absolute deviation	11.08	10.13	9.40	4.70	4.61	4.76
time in system	23.09	23.33	23.66	15.66	16.32	17.03
time in shop	10.80	11.05	11.20	10.73	10.98	11.02
time in pool	1.55	2.74	3.97	1.55	2.71	3.94
M/H time	1.65	1.66	1.66	1.65	1.66	1.66
time in IQ	3.56	3.65	3.72	3.53	3.62	3.68
blocking time	0.06	0.09	0.10	0.06	0.08	0.10
time in OQ	2.01	2.14	2.20	1.97	2.11	2.07
time in FGI	10.73	9.53	8.47	3.37	2.62	2.06
jobs in shop	12.56	12.85	13.02	12.46	12.77	12.80
std. of flowtime	6.63	6.93	7.11	6.57	6.82	6.86
std. of jobs in shop	5.02	5.25	5.36	5.02	5.16	5.18

Table A.45: Simulation results of the modified PRM for different interval lengths under MOD dispatching rule and low machine and transporter utilization.

Appendix B

Anova Tables and Duncan's Test Results

Source	DF	Sum of Squares	F Value	Pr gt F
Model	82	1040227.06	35.90	0.0001
Error	1197	422958.95		
Source	DF	Anova SS	F Value	Pr gt F
B	19	177452.05	26.43	0.0001
U	1	244435.44	691.77	0.0001
T	1	945.86	2.68	0.1021
D	1	4471.69	12.66	0.0004
R	7	279218.62	112.89	0.0001
U*T	1	2398.87	6.79	0.0093
U*D	1	4283.44	12.12	0.0005
U*R	7	241247.74	97.54	0.0001
T*D	1	740.36	2.10	0.1480
T*R	7	36936.02	14.93	0.0001
D*R	7	4504.12	1.82	0.0796
U*T*D	1	749.73	2.12	0.1455
U*T*R	7	34987.82	14.15	0.0001
U*D*R	7	4391.87	1.78	0.0884
T*D*R	7	1710.89	0.69	0.6792
U*T*D*R	7	1752.47	0.71	0.6649

B: Block effect, U: Utilization, T: Due date tightness
D: Dispatching rule, R: Release mechanism

Table B.1: Analysis of Variance for Mean Tardiness

Factor: Release Mechanism (R)

Duncan Grouping	Mean	N	R
A	43.83	160	PINF
B	30.73	160	CINF
C	25.18	160	FFIN
D	11.95	160	IR
E	7.07	160	PAGG
F E	4.53	160	IMR
F	1.17	160	WIBL
F	1.08	160	CAGG

Factor: Utilization (U)

Duncan Grouping	Mean	N	U
A	29.51	640	high
B	1.87	640	low

Factor: Dispatching Mechanism (D)

Duncan Grouping	Mean	N	D
A	17.56	640	spt
B	13.82	640	mod

Factor: Due Date Tightness (T)

Duncan Grouping	Mean	N	T
A	16.55	640	loose
A	14.83	640	tight

Table B.2: Duncan's Multiple Range Test for Mean Tardiness

Source	DF	Sum of Squares	F Value	Pr gt F
Model	82	1407555.42	39.31	0.0001
Error	1197	522673.48		
Source	DF	Anova SS	F Value	Pr gt F
B	19	62341.66	7.51	0.0001
U	1	963771.82	2207.18	0.0001
T	1	106018.64	242.80	0.0001
D	1	20083.85	46.00	0.0001
R	7	43946.26	14.38	0.0001
U*T	1	69473.46	159.10	0.0001
U*D	1	18480.92	42.32	0.0001
U*R	7	55803.21	18.26	0.0001
T*D	1	496.38	1.14	0.2865
T*R	7	12997.22	4.25	0.0001
D*R	7	10329.67	3.38	0.0014
U*T*D	1	477.55	1.09	0.2959
U*T*R	7	10877.85	3.56	0.0009
U*D*R	7	10189.81	3.33	0.0016
T*D*R	7	11023.86	3.61	0.0007
U*T*D*R	7	11243.20	3.68	0.0006

B: Block effect, U: Utilization, T: Due date tightness
D: Dispatching rule, R: Release mechanism

Table B.3: Analysis of Variance for Mean Absolute Deviation

Factor: Release Mechanism (R)

Duncan Grouping	Mean	N	R
A	47.05	160	PINF
B	37.24	160	CAGG
C B	34.38	160	CINF
C B	34.25	160	WIBL
C B	33.15	160	IMR
C D	30.21	160	FFIN
C D	29.78	160	IR
D	26.20	160	PAGG

Factor: Utilization (U)

Duncan Grouping	Mean	N	U
A	61.47	640	high
B	6.59	640	low

Factor: Dispatching Mechanism (D)

Duncan Grouping	Mean	N	D
A	37.99	640	spt
B	30.07	640	mod

Factor: Due Date Tightness (T)

Duncan Grouping	Mean	N	T
A	43.13	640	loose
B	24.93	640	tight

Table B.4: Duncan's Multiple Range Test for Mean Absolute Deviation

Source	DF	Sum of Squares	F Value	Pr gt F
Model	82	6305104.10	59.41	0.0001
Error	1197	1549190.90		
Source	DF	Anova SS	F Value	Pr gt F
B	19	612029.57	24.89	0.0001
U	1	2174452.29	1680.12	0.0001
T	1	99186.57	76.64	0.0001
D	1	1394.95	1.08	0.2994
R	7	1513922.36	167.11	0.0001
U*T	1	95403.62	73.71	0.0001
U*D	1	1718.84	1.33	0.2494
U*R	7	1417135.27	156.42	0.0001
T*D	1	196.14	0.15	0.6971
T*R	7	189500.26	20.92	0.0001
D*R	7	5590.04	0.62	0.7422
U*T*D	1	223.46	0.17	0.6778
U*T*R	7	185274.99	20.45	0.0001
U*D*R	7	5279.05	0.58	0.7705
T*D*R	7	1855.84	0.20	0.9844
U*T*D*R	7	1940.79	0.21	0.9822

B: Block effect, U: Utilization, T: Due date tightness
D: Dispatching rule, R: Release mechanism

Table B.5: Analysis of Variance for Average Number of Jobs in the Shop

Factor: Release Mechanism (R)

Duncan Grouping	Mean	N	R
A	114.11	160	PINF
B	90.84	160	CINF
C	73.30	160	FFIN
D	55.46	160	IR
E	36.84	160	IMR
F	25.86	160	PAGG
G	16.71	160	CAGG
G	13.45	160	WIBL

Factor: Utilization (U)

Duncan Grouping	Mean	N	U
A	94.54	640	high
B	12.10	640	low

Factor: Dispatching Mechanism (D)

Duncan Grouping	Mean	N	D
A	54.37	640	spt
A	52.28	640	mod

Factor: Due Date Tightness (T)

Duncan Grouping	Mean	N	T
A	62.12	640	loose
B	44.52	640	tight

Table B.6: Duncan's Multiple Range Test for Average Number of Jobs in the Shop

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