CHAPTER 2
SCHEDULING THROUGH PRIORITY DISPATCHING RULES -
A LITERATURE REVIEW

2.1 Introduction

The problem of scheduling of resources like operators and machines in manufacturing systems has been studied over the last four decades. Research work has been carried out on the theory of scheduling and its practical applications. Methods based on branch and bound technique, priority dispatching rules, simulated annealing, tabu search, genetic algorithm, artificial neural networks, expert systems, linear programming, integer programming, graph theory, petri nets and Lagrangian relaxation techniques etc., have been proposed. Objectives such as the minimization of lead time and work in process inventory, and maximisation of throughput, resource utilisation and timely delivery have been considered. This chapter reviews the literature on production scheduling and priority dispatching rules.

Panwalkar and Iskander [6] divided the scheduling studies into the following two categories:

- Theoretical research dealing with optimisation procedures.
- Experimental research dealing with dispatching rules.

The theoretical research has aimed at developing mathematical models and optimal or sub optimal algorithms. The theoretical results have not been widely used in the industries due to the high computational complexity of the scheduling problem. The experimental research has been primarily concerned with priority dispatching rules and heuristics that can efficiently solve the scheduling problem.
2.2 Priority Dispatching Rules

The function of a priority dispatching rule is to assign a numerical priority value to each part waiting in the queue of a machine group and to select for processing next, the one with the minimum or maximum value of the priority index. In this section important literature dealing with the priority dispatching rules have been reviewed.

Gere [7] gave the definitions for the various terms used in job shop scheduling. Priority rule, scheduling rule and heuristics are some of the terms defined in his paper.

Priority rule: A priority rule or priority function is that function which assigns to each waiting job a scalar value, the minimum of which, among jobs waiting at a machine, determines the job to be selected over all others for scheduling. In the case of a tie, the job with smaller job number is selected.

Heuristics: They are used to represent a rule of thumb. He also listed the typical simplifying assumptions used in the scheduling research.

Scheduling rule: A scheduling rule dictates which job among those waiting for service is to be scheduled in preference to others. Scheduling a job means scheduling the next operation of the job. Priority rules comprise a proper subset of scheduling rules. A scheduling rule may include one or more heuristics in addition to or instead of a priority rule.

In his scheduling work he used twenty five static problems and sixteen dynamic problems and proposed 11 conjectures. The assumptions made in this work regarding the shop and job parameters are widely used by the practitioners of simulation in the field of job shop scheduling.

Mellor [8] also presented an overview of the various definitions used in the field of job shop scheduling. He reviewed the work of earlier researchers with reference to the scheduling rules and heuristics used and the performance measures employed to evaluate the
scheduling rules. It is a comprehensive review of the work done in the field of job shop scheduling using simulation methodology.

Jones [9] made an economic evaluation of the two priority dispatching rules - SPT and S/OPN (Slack per Operation). He used idle machine cost, cost of carrying work-in-process inventory, cost of long promises and cost of missed due dates as components of the total cost incurred when each of the priority dispatching rule was used. A hypothetical job shop and a particular cost structure was assumed and S/OPN rule resulted in the lowest total operating cost. He also investigated the effect of different levels of work-in-process inventory on the machine utilisation with FCSFS (First Come into the System First Serve), SPT and SNQ (Shortest Next Queue) rules and concluded that SNQ rule resulted in less idle time percentage. He used only a very limited number of rules and only one job structure and cost structure. Hence additional research in this line is required to develop confidence in the conclusions drawn in this work.

Hershauer et al., [10] in their innovative study brought together the techniques and problems available at that time in simulation, sampling theory and computer search. They combined simulation model building, interactive sampling that considered auto correlation, search techniques, and the capability of large computer systems to develop an approach for finding a sequencing rule for the hypothetical job shop considered in their work. They employed the Hooke-Reeves search routine and demonstrated that results obtained with the search procedure excelled the results achieved with any of the standard priority dispatching rules. An important aspect of this study was that the study did not include only one decision factor (such as mean flow time). They used four different factors. A limitation of this approach is the high computation time required to arrive at the good combination rules and coefficients used in the priority dispatching function. But due to the availability of
computational facilities at a lower cost the approach proposed by them can be tried for assembly type of job shops by future researchers.

Rochette et al. [11] compared eight priority dispatching rules on mean flow time and mean tardiness performance measures. They used two-way ANOVA (Analysis of Variance) to uncover the significant factors which produced the process variances and one-way ANOVA for specific cases in order to obtain more information about the influence of the various factors of the process.

Eilon and Chowdhury [12] examined four different due date setting procedures specifying due dates largely dependent on the expected processing time for jobs and the level of congestion in the shop. Three loading rules were used and the combination of the dispatching rules and the due date setting procedures which resulted in good due date performance measures were identified.

Arumugam and Ramani [13] used two cost based dispatching rules along with other traditional rules like SPT and S/OPN. The LVT (lowest value time) rule gave priority to the item having the lowest value for the product of cost value and processing time whereas HVT (highest value time rule) gave preference to the item having the highest value for the product of the above two parameters. The value time rules when compared with other rules on the WIPM (Work-In-Process inventory in Monetary terms) and delivery performance measures did not show any improvement over the existing rules.

Blackstone et al., [14] presented a survey of the measurement criteria used to evaluate the dispatching rules, various models and techniques used in the field of job shop scheduling, and due date assignment procedures. Various aspects related to conducting a simulation experiment were also dealt with that paper. Priority rules used were classified as those based on processing times, due date, critical ratio and combination rules. In addition to that, the
heuristics developed by various researchers up to that point of time were also described. They provided the mathematical formulations for 34 different priority rules. Hence this work serves as excellent survey material in the field of job shop scheduling using priority dispatching rules.

Russell et al., [15] examined the COVERT (C over t) rule in terms of its applicability, sensitivity to various operating parameters and performance measures. Covert sequencing rules is mathematically formulated as $C_i/t_i$, where

$$C_i = \frac{\sum_{i \in \Phi} kw_i - s}{\sum_{i \in \Phi} kw_i}$$

$s = \text{slack}$

$w_i = \text{waiting time for operation } i,$

$k = \text{an approximating factor}$

They utilised three methods of estimating waiting time and two values for the approximating factor, $k (1.0 \text{ and } 0.5)$ and tested against other sequencing rules. The results of the experiment proved that the COVERT rule performed better than all other rules according to due date performance measures. An important limitation of this work is that effect of this rule on other performance measures like flow time, WIP etc., were not reported.

Haupt [16] provided a classification scheme for the priority rules and discussed the relative merits of the different rules for improving the various performance measures. He also discussed the state of the art in the application of the dispatching rules for different kinds of shops like pure job shop and dual resource constrained assembly shop and identified the rules
which are very effective to improve the various performance measures. He indicated that in view of the progress made in the field of computer integrated manufacturing, interaction of sequencing rules on other shop policies such as lot-sizing, lot-splitting, alternate machine selection, overtime usage, work subcontracting etc., can be investigated.

Ramasesh [17] classified the scheduling research based on the nature of job shop as open jobshop and closed shop, based on the nature of requirements as static and dynamic and based on the nature of arrival process as deterministic and stochastic. He also made the classifications based on the research methodology as analytical and simulation research. He also provided a comprehensive review of the various factors related to scheduling research through simulation viz., experimental considerations, initial start up bias, serial auto correlation and the output analysis. Based on a survey of 99 key research publications made in the field of scheduling he stressed that research on assembly-shop scheduling is less extensive although manufacturing shops realistically included some assembly work.

He and Kusiak [18] described three industrial problems from manufacturing systems. In the first case they considered a single machine scheduling problem for which they formulated the problem using mixed-integer programming and solved it using a heuristic algorithm. In the next section they developed a new scheduling rule with the objective of reducing the tool set up time in a machine cell consisting of five lathes and compared the performance of their rule with SPT, FIFO and LPT (Longest Processing Time) rules. The third problem was concerned with the scheduling of laser cutting operation. An important aspect of this work is that the work contained smaller number of variables and constraints than any of the existing formulations and the heuristic algorithm used was of low computational complexity.
Waikar et al., [19] evaluated the performances of ten priority dispatching rules using six performance criteria, under light (70% machine utilisation), medium (77% machine utilisation), and heavy shop loads (85% machine utilisation). The study mainly confirmed the results of the earlier simulation studies and ranked the rules in the order of their performance.

Nagar et al., [20] provided a very detailed literature survey of the solution methodologies used in the field of scheduling, especially the various analytical methods and heuristic procedures. They identified the limitations of each one of them. Simulated Annealing, Tabu search and Genetic algorithms were identified as the potential tools for solving complex scheduling problems. They presented an elaborate classification of the bicriteria and multi-criteria scheduling problems. In their work they considered only regular measures of performance. Non-regular measures of performance were surveyed by Raghavachari[21] and Baker and Scudder [22].

2.3 Dual Resource Constrained Job shops

Most of the research work carried out in the field of job shop scheduling have considered only the machines as the limiting resource and paid no attention to another important resource constraint, namely workers.

One of the pioneering studies in this field was reported by Nelson [23]. He provided a framework for a series of studies on labour and machine limited production systems. He proposed a model including several factors related to labour and job assignment procedures and shop control procedures.

Fryer [24] in his simulation study on a dual resource constraint multi-level jobshop demonstrated that labour control decision at different organisational levels is important in their effect on both flow time and labour transfer measures. A limiting assumption made in
this work was that all workers were equally efficient in operating any machine whereas in practical situations workers are trained to operate only few specific machines.

Weeks and Fryer [25] described a simulation study of the relative impact of due date assignment, dispatching and labour assignment decision rules on the performance of a hypothetical dual-constrained job shop. Six criteria were used to measure the performance of the decision rules and multiple regression was used as the principal method of analysis of the results. They identified significant interaction between the labour assignment and dispatching rules.

Gunther [26] evaluated a number of server assignment procedures within a system of parallel queues. Simulation was used as the analysis tool and three primary results were arrived at:

1) Increasing server transfer time increases mean flow time and the percent of time the server spends transferring

2) Using rules to delay server assignment reduces the mean flow time criteria when compared with rules which do not delay assignment.

3) Delaying server assignment appears to have a greater effect on mean flow time than choosing a particular assignment rule.

Sudder [27] made use of priority scheduling rules and labour assignment policies for a repair shop which supported a multiple item repairable inventory system with a hierarchical product structure and verified that the better priority sequencing rules in the machine limited system are also good in the dual constrained situation.

Norbis and Smith [28] tested a two level heuristic for the resource constrained scheduling problem. At level 1 operations were placed into sets according to the criticality of the path where they occur: first set for the most critical, second set for the next and so on.
Priorities are static at level 1. Level 2 corresponds to prioritising dynamically those operations in each set based on resource utilisation. The heuristic proposed was found to perform well for small size problems and complexity of the heuristic was found to increase polynominally as the problem size increased.

Fellan III et al., [29] compared the benefits realised by the development of a multi skilled workforce with benefits realised by additional workforce staffing. They claimed that developing multi skilled workforce was a more conservative approach and the use of additional labour resulted in a pronounced improvement than the first approach. However, they recommended a combination of the two strategies as the best choice.

Malhothra and Kher [30] investigated the performance of different worker assignment policies in dual resource constrained job shop environments which included features such as the presence of heterogeneous resources and worker transfer delay between the departments. This study was conducted in a more realistic situation whereas majority of the earlier studies assumed identical resources in the job shop.

2.4 Other Issues Related to Simulation

Discrete event system simulation has been used in this thesis as the primary analysis tool. Hence, in this section literature that deals with some of the aspects of simulation has been reviewed.

Law and Carson [31] developed a sequential procedure for constructing a confidence interval for the steady state mean of a stochastic process. The sequential procedures described above were applied to two stochastic models viz., queuing systems and an inventory system. From the analysis of the results it was found that the procedure produced valid confidence intervals in both the cases.
Fishman [32] presented a method for deriving a confidence interval for a population mean from the output of a simulation run. The usual procedure for deriving the confidence interval is to group observations of a run into batches and use these batches as the basic data for analysis. What is new in this method is, the procedure for determining how to group the observations into batches that satisfy certain assumptions necessary for the technique to work correctly.

Once the decision to resort to simulation modelling and analysis of the production systems has been made, the next step is to select the simulation tool to be used in the process. Banks and Carson [33] offered introductory survey and description of the four languages viz., GPSS/H, SIMAN, SIMSCRIPT II.5 and SLAM II and a brief mention of a number of other languages. They explained the perspective of the four languages in greater detail and modelled an example problem using each language. An overview of each solution plus a detailed statement-by-statement description is also available in their paper.

Another important aspect of simulation experiment is validation of the simulation model. It is an extremely difficult and subjective task. A review on the validation of simulation models was made by Law and Kelton [5] but they did not provide any specific practical recommendations. According to Sargent [34], there are no algorithms, procedures, or specific tests for determining the validity of the simulation model. He also brought out four different types of validities:

1) conceptual model validity: determining whether theories and assumptions underlying the conceptual model are correct.

2) computerised model verification: ensuring that the computer program and implementation of the conceptual model are correct.
3) operational validity: determining if the model's output behaviour has sufficient accuracy for its intended purpose or use.

4) data validity: ensuring that the data used to solve the problem are adequate and correct.

Velayas and Levary [35] developed a two phase validation process. The first phase called primary phase occurs when the first simulation attempt is undertaken in any specific project. In this phase using decision theory approach a decision is made whether to go for small, medium or large simulation model. After completion of the initial validation process, in the second phase known as secondary validation, decision theory concepts are applied to identify specific topics to receive the attention they deserve prior to the commitment of additional resources.

The above approach cannot meet the validation requirement in a single shot. They have only shown how decision theory can be used for model validation in the context of simulation.

Ketcham et al., [36] presented an information-based integrated simulation approach for modelling simulation environment called IBIS. Because of its data base orientation, IBIS models were not presented as programming code but in the form of information links stored in a simulation data base. They also described a sample manufacturing problem and the IBIS formulation for that problem. By defining both models and simulation experiments in terms of information relationships several issues in modelling and simulation can be addressed. The information relationships needed to simulate many common manufacturing systems can be established in the database design. The relationships may include the hierarchical definition of stations, and of object classes, flexible product routing and product processing sequences and push and pull drivers for parts flow. The simulation will automatically reconfigure itself when new information is entered into the database. With the availability of powerful RDBMS.
packages at affordable prices the methodology proposed by them can be a very potential tool for analysing manufacturing strategies.

Deslandres [37] presented an application of the expert system technique to validation. The knowledge representation was based on a hybrid formalism using a combination of frames and rules. They also confirmed through a prototype demonstration session how a knowledge based assistance to validation could be possible. The knowledge used in the expert system can be subdivided as follows:

1. Knowledge about the system and the simulation objectives
2. Knowledge of the model
3. Knowledge of data
4. Statistical knowledge

The expert systems focused only on the knowledge base of statistics and data. The prototype for validation was developed basically according to the statistical formulation proposed by Reynolds and Deaton [38].

One of the most important properties that a simulation environment should have is a sound output analysis facility. Mollamustafaoglu et al., [39] analysed the output analysis methods available in the literature and reported how they can be included in simulation environments. They used an object oriented programming system (OOPS). In OOPS the physical and conceptual objects are represented as specific instances of classes. The class hierarchy chart for output analysis methods were listed in their work. The object oriented environment described in their work can be easily used to form a test-bed for various output analysis methods and can be very effective in reducing the total development and maintenance costs.
2.5 Knowledge Based Simulation

Use of Artificial Intelligence (AI) techniques is gaining importance in the field of simulation of manufacturing systems. In this section a review of the literature dealing with use of AI in manufacturing simulation is presented.

Shannon and Mayer [40] provided an overview of the Artificial Intelligence in general and have examined the potential of AI and more particularly, expert systems in simulation. They have also explored the probable directions in which AI can be made use of. It was also forecast that profound changes resulting from the efforts in AI and logic programming for the purpose of knowledge declaration, goal definition and output analysis would have an important impact on simulation.

Haddock [41] developed a simulation generator using Fortran IV subroutines incorporated within the simulation software structure of SIMAN. The system was solely based on the knowledge of the system to be simulated acquired from the user. The expert system framework used in this work can interpret the results of the experimental runs and made statistical inferences about the performance measure. He also indicated that optimisation techniques as suggested by Bengu and Haddock [42] can also be incorporated into the expert system by future researchers to analyse alternative system designs.

Ford and Schroer [43] reported an expert system for an electronics manufacturing plant. In this work the emphasis was given to Natural Language Interface (NLI) that consisted of a transformer and understander. The transformer converted the natural language input into an internal representation. This internal representation was developed from a theory of language understanding based on semantics rather than syntax as proposed by Schank [44]. Once the transformer finishes receiving all the relevant inputs, the understander makes all necessary inferences and understands the complete meaning of the inputs. In other words, the
understander knows what the user desires to be simulated and it begins preparing the input for the simulation writer. These commands are written in LISP and passed one at a time to the simulation writer. In this work use of Natural Language Interface (NLI) and automatic simulation code generator has been successfully demonstrated with a sample problem.

Chryssolouris et al., [45] in their work used AI, particularly Artificial Neural Networks (ANN) to determine the best operational policy for a specific manufacturing system. Simulation results were used to train a neural network which then prescribed an operational policy suitable for achieving a set of goal performance measures.

The proposed neural network was unique in that it determined suitable criteria weights for an entire sequence of multiple-criteria decisions.

Nolan et al., [46] presented an expert system interface to general purpose simulation languages, ISI (the Intelligent Simulation Interface). The ISI software provided an interface to SIMAN - a general purpose simulation language and was implemented in muLISP-87 [47]. A hierarchical approach was used to construct the simulation models. In this approach, the system was broken down into a network of interconnected subsystems or macros. Macros were constructed by selecting a part of an existing model and shrinking it into a macro. A case study was also presented which described a practical problem, and illustrated the ease with which complex simulation models can be generated using ISI and a general purpose simulation language.

Baid and Nagarur [48] provided an overview of the Intelligent Simulation Systems (ISS) and its different modules. AI based modelling approaches were categorised as follows:

- Object Oriented Programming
- Logic Programming and
- Hybrid Methodologies
An overview of Petri Nets (PN) for analysing manufacturing systems has also been given in this work. It was also concluded that an all purpose general ISS was probably not feasible and they predicted that the future systems would have to be domain specific.

Merkuryeva [49] reviewed the state of the art in knowledge based simulation systems (KBSS). More than 50 examples of research and commercial systems were given in the form of tables. The various perspectives for KBSS development viz., on-line digital control, simulation modelling and database management, development of parallel and distributed systems, fuzzy simulation environment development, combination of the expert system capabilities with potential for adaptation by artificial neural networks have been discussed.

2.6 Assembly Shop Scheduling Using Priority Rules

Maxwell and Mehra [50] used multi-level "Symmetric tree structured" jobs in their experiments. They tested the performance of four basic priority rules and a variety of composite rules constructed from the four basic factors. Mathematical formulations for those factors are as follows:

- **Operation Slack Factor (OSF)**
  \[ (Q_{i,j,l} - P_{i,j,l} - R_j) \]  
  \[ 2.2 \]

- **Processing Time Factor (PTF)**
  \[ P_{i,j,l} \left( \sum_{j=1}^{N} \sum_{i=1}^{D} P_{i,j,l} \right)^{e} \]  
  \[ 2.3 \]

- **Operation Urgency Factor (OUF)**
  \[ x_j(D)^{e} + x_j(N)^{e} + x_j(J)^{e} \]  
  \[ 2.4 \]

- **Procedure Constraint Factor (PCF)**
  \[ x*_{i} h*_{i} \{ \max (p_{i,j,l}) - p_{i,j,l} \} + y^{*}_{i} \} \]  
  \[ 2.5 \]

\[ x_{i}, x_{j}, x_{k}, b, c, d, f, g, h \] are constants
\[
x = 0, \text{ if the operation is the final operation of the job.} \\
= 1, \text{ otherwise}
\]
\[
y = 0, \text{ if the operation is one of the initial operations of the job, i.e on level 1} \\
= 1, \text{ otherwise}
\]

Maxwell [51] tested the performance of several priority rules with respect to mean lead time, mean flow time and mean staging delay and other performance measures. Among the rules he tested NUSEG (Number of remaining Segments) priority rule had the best performance with respect to the mean staging delay. When combined with SPT as a tie breaker, this rule resulted in an improved overall performance. He concluded that, further improvements in performance could be achieved by using a priority assignment procedure that incorporated the dynamic progress of the job segments as they proceed through the shop and also by making use of the SPT as a tie breaker. He utilised job shops where only single-level assembly jobs were considered. Each job had the same number of segments whereas in a typical job shop the incoming jobs may have different number of segments and sub assemblies at different levels.

Sculli [52] has used the same set of priority rules used by Maxwell [51]. He experimented with the rules in a hypothetical assembly shop with the following modifications:

(1) Number of parts per job was allowed to vary
(2) Final assembly operation was included
(3) The average number of operations per part was reduced from nine to five
(4) Random delays were allowed to occur
Actual operation time was used as a random variable with mean value equal to the estimated (standard) time. He also studied their performance under different shop loads. In this work also the jobs with sub assemblies at only one level were considered.

Goodwin and Goodwin [53] made an investigation on priority dispatching rules in a hypothetical assembly shop with the main objective of examining whether the research on non-assembly environments can be generalised to assembly shops also. In this research work assembly jobs made up of assemblies at more than one level were considered for the first time. They also considered products with subassemblies at three and four levels. For setting the release dates they used two methods: total work content method and constant allowance method. In the constant work content method release date was calculated by multiplying the total work content of a job and subtracting this value from the order's due date. In the constant-allowance method release date was calculated by subtracting a constant allowance from the due date. Once orders are released for production, six procedures are used to calculate priorities, one based on the service time of the order, two based on the due dates, two based on slack, and one based on the status of the order in the production system. They used both mean lead time performance measures and mean due date performance measures. Use of statistical tests (F test) to analyse the simulation output was demonstrated in this work. One of the most interesting findings of the study is the identification of strong effect of combining the rules together to form policies.

Huang [54] extended the previous research in the area of assembly shops, by including both serial and serial-parallel operations in a production system. As an example for this kind of shops he quoted the auto parts fabrication shop which may supply not only basic components, but also subassemblies to assembly plants. Staging delay as a component of the job lead time was also an important concern in this type of hybrid system. He reported the
results by changing the percentage of assembly jobs in job mix from 20% to 40%. Results of the analysis indicated significant impact of the two factors studied; product mix and priority rule. The interaction of the two factors was found to be significant. It was also observed that the ranking of a priority rule got altered when the percentage of assembly jobs was changed.

Russell and Taylor [55] evaluated the following eleven rules out of which some are common to job shops and some specifically designed to assembly shops using a simulation analysis of a hypothetical assembly shop:

FCSFS, SPT, EDD, TWK(Remaining Total Work Content) , ROPT²(Remaining number of Operations), SP(Shortest Path), BS(Branch Slack), TWK+SC(Shop Congestion factor), ROPT²+SC, BS+ROPT², LP(Longest Path) +ROPT² .

The simulation results were analysed using ANOVA procedure. Since ANOVA results were found to be significant, Tukey studentised range multiple comparison test was performed at the 5% level to reveal where significant difference in performances among sequencing rules occurred. BS+ROPT² and LP+ROPT² were the specialised rules used by them with the addition of a stabilising factor-ROPT²-to the existing rules. These rules were not tested earlier. They claimed that EDD rule performed well or better than any other rule in reducing the mean flow time and that LP+ROPT² rule performed better than all other rules in reducing the mean assembly delay. The investigations were carried out at only one machine utilisation level and the effect of increasing or decreasing the machine utilisation level on the relative performance of the rules was not investigated.

However only Russell and Taylor [56] investigated the dual resource constrained settings for assembled products for the first time. They examined due date assignment procedures, labour assignment procedures, and item sequencing rules. The sensitivity of these policies to product structure was also addressed. Experimental results were analysed using
ANOVA procedure to determine the effect, if any, of the various factors on root mean square of tardiness of completed jobs. A Tukey multiple comparison test was performed at the 5% level for the means of all main effects and the significant interaction effects of RMS of tardiness.

A very important contribution made by Adam et al., [57] in their work on assembly shop scheduling is the development of two indices called relative remaining processing time (RRP) and relative remaining operations (RRO) index.

The general mathematical formulation for finding the RRP index for the $m$th subassembly of the $n$th subassembly of the $l$th assembly is given by:

$$
RRP_{lmn} = \frac{1}{J_{(l)m}J_{(m)n}} \left[ \sum_{i \in S(K_1)} P_i + \sum_{i \in S(K_1)} \sum_{j \in S(K_2')} P_{ij} + \sum_{i \in S(K_1)} \sum_{j \in S(K_2')} \sum_{k \in S(K_3')} P_{ijk} \right] - \frac{1}{J_{(l)m}} P_l - \frac{1}{J_{(m)n}} P_{lm} - P_{lmm}
$$

The RRP index for those subassemblies that have no subassemblies:

$$
RRP_{ln} = \frac{1}{J_{(n)m}} \left[ \sum_{i \in S(K_1)} P_i + \sum_{i \in S(K_1)} \sum_{j \in S(K_2')} P_{ij} + \sum_{i \in S(K_1)} \sum_{j \in S(K_2')} \sum_{k \in S(K_3')} P_{ijk} \right] - \frac{P_l}{J_{(n)m}} - P_{lm}
$$

The RRP index for those assemblies, in a three level job structure that have no subassemblies:

$$
RRP_l = \frac{1}{J_{(l)m}} \left[ \sum_{i \in S(K_1)} P_i + \sum_{i \in S(K_1)} \sum_{j \in S(K_2')} P_{ij} + \sum_{i \in S(K_1)} \sum_{j \in S(K_2')} \sum_{k \in S(K_3')} P_{ijk} \right] - P_l
$$
where, \( J_{(l,m)} \) = total number of subsubassemblies in the \( m \)th subassembly of the \( l \)th assembly

\( P_{(l,m)} \) = Processing time of the \( l \)th subsubassembly of the \( m \)th subassembly of the \( n \)th assembly

\( J_{l} \) = number of subassemblies in \( l \)th assembly of the job

\( S(K_j) \) = the set of subassembly segments that are on the \( j \)th assembly

\( S(K_{ij}) \) = the set of sub-sub assembly segments that are on the \( j \)th subassembly of assembly \( i \).

Similarly RRO index can be found out by replacing the processing time with the number of operations. They used this index to break the tie while dispatching the items to be scheduled using dynamic TWK and NUSEG version of the rules. It was found that these rules performed better when combined with these indices for breaking the tie.

All the investigations reviewed in this section deal with only hypothetical assembly shops by bringing the essential features of a job shop manufacturing multi-level assembly products into the model. Townsend and Lamb [58] simulated in detail a furniture manufacturing plant to evaluate the effects of various proposed changes as a long term production planning tool. An important feature of this work was that a very detailed model of the specific plant was constructed and the size and complexity of the model and the diversity it contained was very large. The investigations were carried out on the following three topics:

(i) Job Priority Rules : The priority rules tested are a small sample of the priority rules available. Using tardiness as the measure of systems performance, in particular the tardiness of the final operation performed on each batch, the SPT was found out to be the optimum rule of those tested.
(ii) Bottleneck evaluation: Through simulation it was found out that some resources were overloaded and some other resources were under utilised. Hence, by trial and error the optimum combination of additional number of shifts for various resources and overtime work load were identified.

(iii) Automation: A proposal to automate a particular machine was investigated and it was identified that for the options tested and for the same system performance, labour utilisation decreased when automation was added. While only a specific plant was simulated, the model contained many general features, and the considerations and problems seemed to be quite common.

Adam et al., [59] studied due date assignment procedures in job shop environments processing multi level assembly jobs. Due dates were assigned internally. They introduced a dynamically updated due date assignment procedure where the appropriate coefficients were continually updated to reflect the changing job mix and work load. This dynamic updating based on average job lead time information provided better performance than all other static due date setting procedures.

Tiwari and Rajendran [60] proposed a new scheduling rule for scheduling in a job shop involved in the manufacture of components and sub assemblies for aircraft accessories. They formulated a job priority index as the sum of the following three indices:

(i) Slack Scale Value (SSV), for job \( i \)

\[
(i) \text{Slack Scale Value (SSV)}_i = \frac{-(\text{slack})_{i} - \min_{i} (\text{slack})}{\max_{i} (\text{slack}) - \min_{i} (\text{slack})} \quad 2.9
\]

(ii) Notional Assembly Level Scale Value (NALSV), for job \( i \)

\[
(ii) \text{Notional Assembly Level Scale Value (NALSV)}_i = \frac{(\text{NAL})_{i} - \min_{i} (\text{NAL})}{\max_{i} (\text{NAL}) - \min_{i} (\text{NAL})} \quad 2.10
\]
(iii) Process Time (PT) Scale Value (PTSV) of job i

\[ \text{PTSV}_i = \frac{(\text{PT})_i - \min_{i,j} \text{PT}}{\max_{i,j} \text{PT} - \min_{i,j} \text{PT}} \]

where, \( j \) = set of jobs awaiting at a given work centre

The job with the least value for the overall priority index would be preferred for loading on a given work centre. The results indicated that the rule proposed performed better than the existing rules in reducing both the lead time and total tardiness values.

2.7 State of the Art

A thorough analysis of literature on the priority dispatching rules for scheduling in manufacturing environment, application of artificial intelligence in simulation and other issues related to simulation of manufacturing systems reveals the following:

a) The bulk of the research papers deal only with scheduling of job shops processing string type of jobs.

b) The analytical techniques were used to solve only static problems and they were not successfully applied for solving continuously arriving assembly type of jobs.

c) Since analytical techniques are capable of conveniently solving only static and small size problems, discrete event simulation technique has been used by all researchers for analysing the manufacturing systems where jobs arrived continually.

d) Not many research studies have considered multiple objectives whereas the industries are interested in improving a number of performance measures such as the adherence to delivery schedules, the reduction in lead time and work-in-process inventory simultaneously.

This review indicates the scope for further research in the area of scheduling in jobshops processing multi-level assembly jobs and the need for formation of better...
dispatching rules for this purpose. An elaborate comparative study of the prominent rules based on key performance measures also needs to be conducted.

2.8 Summary

In this chapter a comprehensive review of literature in the field of job shop scheduling using priority dispatching rules, dual resource constrained job shops, assembly shop scheduling and the related issues have been made. The deficiencies in the current state of art have been identified and the need for doing research in those areas are established.