Factors of Production Throughput Improvement of Flexible Job Shop with Hybrid MTO-MTS Production Strategy Through Production Scheduling Using Dispatching Rules and Simulation; Case of Deluxe Furniture Manufacturing, Minaye P.L.C

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Author's Declaration

I, Eskedar Negese, declare that this thesis entitled "Factors of Production Throughput Improvement of Flexible Job Shop with Hybrid MTO-MTS Production Strategy Through Production Scheduling Using Dispatching Rules and Simulation; Case of Deluxe Furniture Manufacturing, Minaye P.L.C" is my original research work and no material has been submitted previously for the award of any other academic degree.

The research work was done under the guidance of Dr.Ermias and Mehret (PhD candidate) at Addis Ababa University, Addis Ababa Institute of Technology School of Mechanical and Industrial Engineering.

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Dr.Ermias Tesfaye ______________ Signature Date _______________

Table of Contents

Table of Contents

List of Figures

List of Tables

Abstract

For the past few decades, the production schedule has been the focal area for researchers under different production types and respective strategies being implemented on. Among the previous researches, the partial flexible job shop scheduling problem with the concept of the production strategy implemented on hasn't brought to the academic research as well as practical based research development areas. Based on the reviewed articles and studies, it has been identified that there exists certain gaps on the production scheduling of a partial flexible job shop production floor type and the strategy implemented.

The need for this concept is to clearly define methods using the production scheduling to indicate on how to manage the natural constraint conflict taking place on this very kind production floor type. In meantime, support the implemented strategy to improve the throughput and other performance parameters such as capacity to accept new orders, WIP accumulation percentage and number of tardy job orders.

Thus, this paper will be proposing production scheduling using dispatching rules integrated in simulation tool. The throughput improvement is achieved as a result of to the factors of improved work-in-process ("WIP") accumulation % and tardy number of job orders. The study is conducted based on clear understanding of the existing production scheduling and developing consistent production scheduling policy, strategy and methods using the above mentioned tool in representing the operating system and respective scheduling model. The overall aim of the study is to propose suitable production scheduling using dispatching rules to concisely developed for the production nature under the study; and simulation tool to exhaustively representing the production floor. As a result improve the number of tardy jobs as well as other neglected performance metrics: capacity to accept new orders, WIP accumulation percentage and throughput of the production floor.

***Key words**: real time production scheduling, hybrid MTO-MTS production strategy, partially flexible job shop, minimize maximum tardiness and completion time, reduce the WIP accumulation rate and improve throughput.*

Chapter 1

Introduction and Problem Justification

1.1 Introduction

In general, industry is composed of interrelated and interdependent decisions in order to give out the final product in terms of goods and/or service to the customers. These final products are based on their requirements and also well identified expectations. Of course, the commonly expected final result out of a given system is to make profit and become competitive in the business sector through meeting and exceeding the market requirement and expectation. In the case of manufacturing industry firms, this market competitiveness highly depends on the efficiency of the production subsystem. Production subsystem is one of the core component relative to the other subsystems that are integrated to form the whole system of the manufacturing. The production planning and scheduling is taken as the backbone of the production floor which is designed to convert raw-material/work-in-process to finished goods/product in an optimized way.

Production scheduling is a set of operational decisions to manage proper allocation of the available resource in a way to smoothen the production flow. Parallel to this, it lessen the tension created due to resource conflict caused by certain defined constraints such as machine capacity, manpower skill, financial and material restrictions. All the above mentioned constraints have different traits and/or features that can be reflected under a given production type and strategy implemented on the production floor. Therefore, the need for an appropriate production schedule has the potential to drive managerial level decisions based on the performance recorded in the production process. For this reason, the academic as well as manufacturing sectors have given serious emphasis on how the production schedule is developed and implemented according to the production floor nature, plan and capacity. At the beginning of the production scheduling the focus of researches were mainly static, single machine based and single performance metrics/objective. But due to the time factor and inevitable technology evolution, the production scheduling scope broaden to incorporate the dynamic product order arrival. Additionally, the different production floor type and effect of variety vs volume of products and other related events have become additional focus area. As a result of this, the methods used to define and develop production scheduling problems have changed and become better with flexibility. This is achieved as a result of technology advancement and academic concern issues. The application of production schedule and respective decision is no longer limited to the entities found in the production floor. Instead of this, it has been identified as control and monitoring mechanism even along the upward decision path where the production floor type and strategy formulated to attain the planned and stated objective of the whole system-production or service. In parallel to this, requirements to develop the production schedule for a specific production type and strategy have changed; so do the methods used. For instance, the concern to include real time update for rescheduling under dynamic production job order entertaining production floor. The potential methods that fits to organize, evaluate and analyze these data also introduced to the field of study. Peeters & van Ooijen, (2020) A recent taxonomic review on the hybrid MTO-MTS production strategy depicts that the conceptual definition and understanding of the applicable production strategy governs the production scheduling methods and tools to use. Hence, in depth understanding of a given production floor along with the miscellaneous practices adapted it needs to be considered in optimizing the overall production performance.

This paper has identified production scheduling problems in the job shop type of furniture production floor where there exists partial flexibility of the operational process as there are a variety of products and exercise hybrid production strategy. The production strategy is make to order (MTO) and make to stock(MTS). The objective is to come up with the suitable production schedule using priority decision rules and improve the throughput using the factors affecting the performance. These scheduling rules are devised in a customized way to technically address the factors affecting the resource conflicting in scheduling and sequencing on the production floor. This develops a baseline schedule in a way it is consistent based on the status of the production floor. For the performance analysis and clear representation of the production process a simulation tool is incorporated to construct the model; as a result of this improve the throughput as well as certain performance metrics such as work-in-process (WIP) accumulation percentage and number of tardy jobs in the dynamic and stochastic processing nature -with adopted hybrid MTO-MTS production strategy- in the scheduling of the job orders.

The relevance of the study towards the field-industrial engineering- is that it provides additional insight on the concepts to consider while developing for better production scheduling method. These insights are production type and implemented strategy compatibility. Of course, these can significantly bring improvement on the overall performance and also operational decision mechanism in use. In the context of the academics as well as practical advantage, in the reviewed literature articles the simulation models that have been developed so far lack detailed representation on the model. Thus this presented model can be used for further parameter measurement focused study by modifying the model. Similarly, indicate potential key performance indicators for such production and respective data-base development to improve the performance as a system using production scheduling approaches.

1.2 Background of the study

The selected firm for the research is a furniture manufacturing industry Deluxe Furniture. It is well known for its both imported and import substitute products in the furniture industry sector found in Ethiopia. The company has a variety of products in material type being used, design and measurement specification. For this nature of the production feature, the manufacturing production floor is designed as a job shop with partial flexibility to maintain the overall manufacturing efficiency. Due to the volatile market and customer behavior, the preference on custom-made products take over the market competition; thus, Deluxe Furniture began to adopt the hybrid make-to-order (MTO) make-to-stock (MTS) production strategy. This strategy has enabled the company to entertain both customer order and stock based delivery simultaneously. As a result of this, it has established sustainable market share in the industry sector with quality which customers aspire to have. Based on the work measurement and time study conducted by the production team, it is verified that the production is capable of entertaining these two production strategy simultaneously. However, beside the machine and other required resources, the operational and managerial level decision effect haven't been considered. This is demonstrated in the active practice where the production scheduling is tightly integrated with that of the planning. Consequently, this practice leads to less performance on the selected production performance metrics and other related issues have also become problems that need solution. Furniture and automotive assembly manufacturing are the most well-known job shop production types whereby a single production strategy applied and predictive based scheduling is outlined. But, through the dynamic nature of the market as well as ever changing production technology, there is not a complete single production strategy applied. In general, this implies that across different production types the percentage of the hybrid production strategy varies yet pure production strategy can't be capable of performing as efficiently as designed. Therefore, similarly the production scheduling needs to relate with the selected production strategy as it highly affects the performance parameters of the production process. Since jobs under the make to order have high customization, the jobs under the make to stock encounter maximum tardiness and also high WIP accumulation rate per the transferred job order in the production floor. Thus, the operational decision such as production scheduling is a critical solution finding mechanism to adjust the practical gap and issues even in the upper level. Hence, a clear gap statement of this leads to detail study of the dynamic nature of the production caused by different events such as: random arrival of jobs without advance information such as completion time, number of parts, number of process and time and frequency required to do set up adjustment in order to initiate and run the production. In addition to this, the existing production scheduling lacks consistency and pre-defined guidelines to forward a factual based approach of decision making.

Deluxe Furniture products are classified as Home, Office and Kitchen furniture from the product knowledge reference and a total of 107 product varieties being produced under both order and stock strategy, in relative selection for stock based on the demand and sales rate- fast moving items.

Table 1 Number of product types across each category for MTO and MTS production.

Product category	**Number of product type**	**Number of product type for MTO**	**Number of product type for MTS (fast moving items only)**
Home	35	-	-
Office	59	59	22
Kitchen	13	13	9

Each product category has sub-category for the various product types and the variety is only based on size and design which affects number of parts and operational sequence in the production; the sub-categories for each major product category selected for this study are as follows:

- ❖ Office: computer table, standard table, conference table, pedestal, computer and printer table, standard table, coffee table, workstation, file cabinet, side return, open shelf, GZ-family with metal leg.
- ❖ Kitchen: upper kitchen cabinet, lower kitchen cabinet and tall kitchen cabinet

The production report summarized under these categories for the last production year- 2013 E.C. Majority of the production share is Office and Kitchen lastly Home furniture products.

Table 2 Annual production of product category

Annual Production- 2013 E.C.		
Category of Product	**Quantity of production**	**Degree of product variety**
Home	584	High
Office	3645	Medium
Kitchen	8114	Medium

The study proposing suitable production schedule for the above mentioned application area provides deep and clear insight on solving the problem of reducing maximum number of tardy jobs and percentage of WIP accumulation and how this improves the throughput of the production system. As a result, the baseline scheduling will get the chance to be revised whenever continuous improvement concerns are proposed for better performance as a function of time. Also indication on how to use technologically advanced tools and techniques in order to eliminate and/or reduce other performance metrics inefficiency and compete for standardized production process and quality products.

1.3 Problem statement

Job shop production type is the type of production that is capable of entertaining such complexity of a given production process as a system majorly goes through the production scheduling decision. Similarly, it is a production type where the strategy, policy and methods determine its performance. Thus, it clearly indicates how the production planning and scheduling affect the overall performance of the production floor. Similar to this concept, the case study-Deluxe Furniture Manufacturing-exhibit the above mentioned features: hybrid MTO-MTS production strategy with partial flexibility in the job shop production floor setting. But, the adopted and existing production scheduling due to the method/technique and tool used lacks consistency as well as reactive nature when the production process is subjected to any disturbance caused by potential events. These potential events are the arrival of random new job orders, rush/urgent order arrival, accumulation of WIP inventory on the production floor and so on. In addition to the known attributes of a job shop production type, the adopted production strategy influences how the production floor operational decisions are made-similarly the strategy, policy and methods- in order to attain the planned performance in the production process. These performances can be production efficiency, optimum utilization of the available resources, and quality standard for each product and also to become a competitor in the market through meeting and/or exceeding customers' requirement and expectation respectively.

For the problem under this study, the production scheduling is mainly generated based on a very long time experience and knowledge of the manufacturing area. Basically, it is based on the commonly used dispatching rules-first in first out, shortest processing time, volume of production-and somehow adjusted rules developed by the line and/or production managers in time of decision making. These rules are customer priority, board waste minimization and total machine requirement. The observed problems are namely long completion time, continuous accumulation of WIP inventory on the production floor, increased number of tardy jobs and lower throughput volume compared to the planned as well as the production shop floor design. These have found to be a real challenge and hinder the capacity of the production floor to accept new job orders and sequencing the already scheduled job orders directly or indirectly. Due to these problems, the production throughput is lower than the production capacity defined by the production team work study, as a reference. The completion time for the released output is two times (the max average time required is 55% of 457 days) and the production floor occupied with the tardy jobs most of the time. From the data collected from primary and secondary source analyzed the production floor has an average of 80% WIP accumulation percentage and the time between immediate and scheduled production is 19 days. This shows the order acceptance capacity of the shop floor. The undefined based production scheduling yields 35 products/day.

Table 3 Type of job vs performance table

	Performance Parameters	
Type of job orders	WIP accumulatio %	Accepting new orders interval(Days)
Urgent job orders	34%	~7-19
Scheduled job order	48%	~15-20

Similarly, so far in the academic research as well as manufacturing practical experience, production scheduling for job shops from different prospective studies and proposals has been set forth to be implemented for different improvement objectives. These objectives are mainly to enhance the customer satisfaction and gain larger market share in that particular industry sector. Of course, in the past three decades significant improvements in job shop- total and partial flexible- production process have also obtained especially on the key performance indicators such as flow time, completion time and maximum tardiness, machine capacity, energy consumption and so on (Boyer et al., 2021; Ghaleb et al., 2020; Thenarasu et al., 2022; Wang & Lu, 2021).

Thus, in the case of hybrid MTO-MTS production strategy the accumulation percentage of WIP and the low volume throughput of the production floor observed as challenge since the production scheduling is, almost most of the time, subjected to two decisions. The decisions are accepting new job arrival and scheduling the job order based on the operating status of the production floor at that particular time. Since there are a variety of products, the number of parts to process, number of operations, processing and set up time varies from product to product baseline scheduling is required to change in order to align the desired objective achieved through rescheduling. This approach can also reduce the WIP inventory accumulation percentage and helps the operators to make decisions to accept and schedule the new job arrivals based on set of criteria and current operating status.

1.4 Research questions

As per the nature of the production floor- partially flexible job shop (P-FJS) with hybrid MTO-MTS production strategy, the identified problems are significantly affecting the potential throughput which can be caused by the other two mutually dependent performance metrics: WIP inventory accumulation percentage and number of tardy jobs. Hence, the following are the research question to initiate this study:

1. What scheduling method/technique and tools can be used in scheduling this particular production floor-partially flexible job shop with hybrid MTO-MTS production strategy?
2. How is the existing production scheduling affecting the key performance such as WIP inventory accumulation percentage, number of tardy job orders and throughput of the production process system.
3. Which dispatching rules to develop from and to be used in the simulation modelling of the production scheduling for partially flexible job shop production with hybrid MTO-MTS production strategy?
4. What approach to use in order to clearly structure the model representation of the production floor in both the existing and proposed dispatching rules in parallel with the analysis obtaining mechanism?

1.5 Objectives

1.5.1 General objective

The main objective of this study is to propose suitable production scheduling for the partial flexible job shop with hybrid MTO-MTS strategy through improving the factors of production throughput and WIP accumulation using dispatching rules and discrete event simulation.

1.5.2 Specific objective

In order to achieve the stated objective through answering the research questions the following points are the detailed procedural description throughout conducting the research. The specific objective are:

- ❖ Clearly understand the operation of the production floor to get information on how the production floor is entertaining the hybrid MTO-MTS production strategy simultaneously and analyze the existing production scheduling methods of production floor performance parameters.

- ❖ Develop criteria to select product types to be used or considered as a variety of products produced and define the key performance metrics as whole for the type of production floor under study.

- ❖ Craft suitable dispatching rules that incorporate practice and nature of the production floor and respective tool for analysis in a way it focuses on the objectives set for optimization with an understanding of the potential application scenarios and to reduce resource conflicts in scheduling and sequencing.

- ❖ Finally propose the best performance dispatching rules that fits the multi-objective focused production floor performance in various yet historical benchmarks of the production operation scenarios.

1.6 Scope and Limitation of the study

1.6.1 Scope of the study

The major focus of the study is in the production floor. The study does not consider material supply as well as cell layout. Since the manufacturing plant has a wide variety of product items, selected product items are considered in the research based on the demand volume and forecast of the production plan. As the identified problem leads to suitable production scheduling, most of the primary and secondary data will be taken from the production floor and respective departments. Similarly, the constraints exist in the production floor only, not rather from other interrelated departments such as raw material warehouse, finished goods inventory and marketing.

1.6.2 Limitation of the study

The focus area of the study is limited to the issues concerning the production floor and related interaction. Therefore, the following issues haven't been considered: machine unavailability, shortage of raw material, buffer size limitation, demand fluctuation, manpower skill has not been covered while proposing the new dispatching rules.

The study is limited to the resource conflict that takes place in the production floor due to the applied production scheduling unable to align/match with the production strategy it is set on to run; thus, unavailability of machine, shortage of raw material, manpower skill, maintenance activity and demand fluctuation has not been considered while proposing the real time rescheduling based production scheduling.

1.7 Significance of the Study

In the manufacturing industry there are different levels of decisions based on the management level; and production planning and production scheduling are the types of decisions carried out at the medium/tactical management level and lower/operational management level respectively. These two decisions can be an input for the strategic level decisions as they indicate the performance of the actual production process in terms of various performance parameters compared with the planned and set on the strategic paths. Therefore, the significance of precise and appropriate decision on these sections imposes on the general plan and strategic roadmap outline of the whole manufacturing company. In addition to this, the study can be used as input for the academics further research area by including the concepts defined as limitation of this study, newly designed DR for the activated production described here. Even though there have been a number of production scheduling- job shops with flexibility and hybrid concept of the production strategy- problems solved using DR, the need to make it suitable and closely applicable with consistency will provide better outcomes to manage the production with exact production strategy.

In parallel to this, the production type and active strategy determines how these decisions are made for different scenarios and conditions where there will be a chance to make adjustments using the time of action status of the production across the operating setup of production. Flow shop with one type of production strategy- either make to stock or make to order based on production forecast- for production or assembly has already studied and suitable solutions have provided considering the objectives; utilization of machine capacity, minimization of makespan time and maximum tardiness and also holding time of WIP inventory across work sections. Similarly, partial or total flexible job shop production scheduling based study has been conducted with the same objective parameters. However, the study of partial flexible job shop production scheduling where hybrid MTO-MTS- with exact conceptual definition of the production strategy- production strategy being exercised hasn’t come to the academic study even though there are manufacturing companies with this nature and set up in the real world operating environment.

Therefore, conducting this research will address gap identified in both the academic and practical scope in regard to the application of DR- on prioritizing job orders with features of random and rush job order nature, partial flexibility on operation processing route- and integrability with a simulation analysis tool to evaluate the performance of the existing and proposed dispatching rules based on the performance metrics subjected to be optimized as an objective of the study. Along the process, the existing production system set of challenges can be mitigated through the proposed DR while accepting and scheduling new arrival job orders and its impact on the throughput- with tangible and scientifically studied solution meanwhile indicating further research study area such as machine break-down, electric energy consumption, layout, buffer space and transportation cost so on in this particular production type and feature.

Chapter 2
Literature Review

2.1 Introduction

In the past two to three decades, the production scheduling in the job shop production floor has been the major focus in relation to the optimization-based focus areas. However, the existing gap both in terms of theoretical as well as practical left with in-depth research demanding status (Soman et al., 2006). In the concept of the production planning and control segment optimization focused studies, the production planning and controlling mechanism alignment is mostly considered as incorporated and well complementary for the optimized system to be modeled. But, given the reality of production scheduling, especially in the job shop production floor, the assumptions made on the policy stated and the strategy implemented hindered the applicable capacity of the optimized system proposed under scientific studies (Peeters & van Ooijen, 2020). As mentioned almost in all job shop production scheduling literatures, the job shop scheduling is treated as non-deterministic polynomial hard type to compute and define a solution to make decisions by. In addition to this, the type classified based on the process route flexibility and this set the scheduling problem to further complexity. Also studies emphasize that production scheduling as one of the critical issues in the planning and management of manufacturing process. Furthermore, the job shop type of production floor case of scheduling has intensified the nature of searching for solutions in the problem solving of job shop production scheduling.

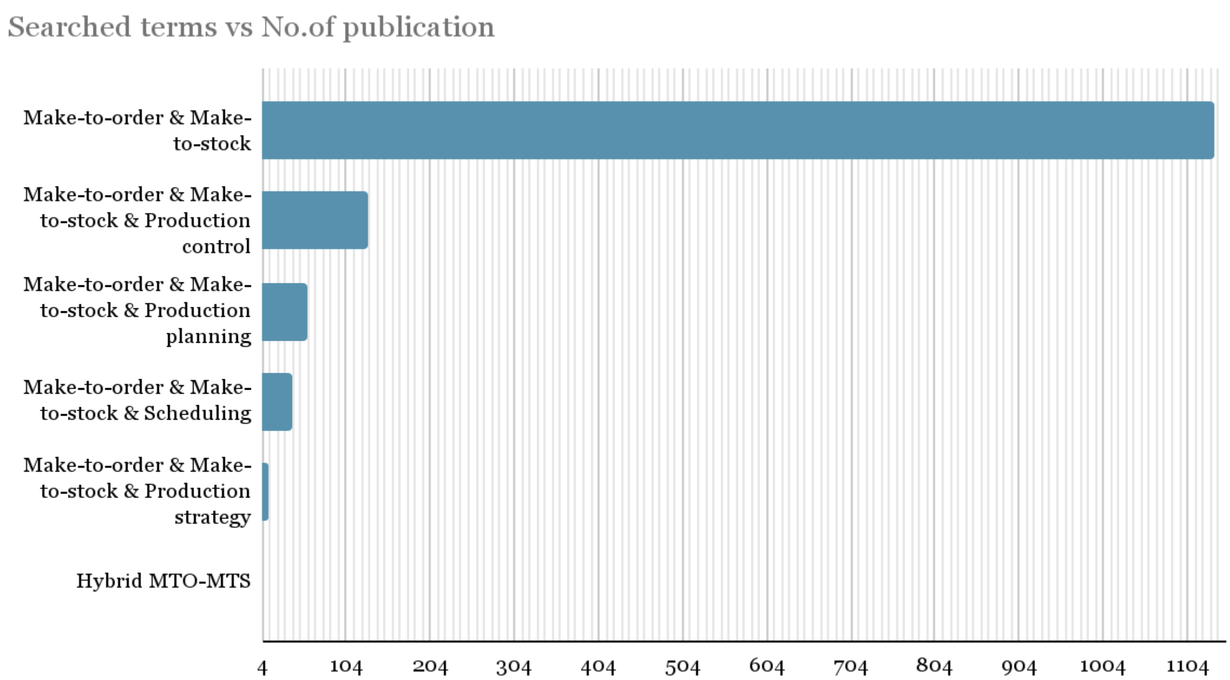


Figure 1 Searched terms vs No. of publications

2.2 Job shop and production scheduling

Turker et al., (2019) states that in this production type-job shop- mostly the production is carried out according to the customer's order and the due date set from external. Since the variety of products is high and production volume is low, the machines are designed in a way to execute a set of operations of different products for each of them that have a defined route of processing. The coordination of production resources in this production floor is often difficult to manage. The term of this coordination in the production floor is production scheduling and it plays a vital role in utilizing the available resources efficiently and in an optimized way.

Production scheduling of a job shop is required to align with further detailed concerns of the production floor such as: the job order arrival pattern, buffer size of machines, set-up and change-over time of machines, machine breakdown interval, bottleneck of the process line and more so as to incorporate the real production environment and control accordingly(Turker et al., 2019). In similar to this concept, the need to have advanced production scheduling in order to incorporate the influencing factors of the production controlling mechanism has become the core value of the production scheduling. Especially in a job shop production scheduling problem. In return, this enhances the capacity to develop compatible as well as reliable production scheduling which can manage production process activities and decisions. As with other studies, (Holthaus & Rajendran, 1997) mentioned how the scheduling is critical and a focus of interest in the job shop floor management and overall production performance controlling aspect. Scheduling is treated as the decision core of the production floor in managing the achievement of the objectives that are formulated through an optimized assignment and sequencing of job operations. One way of tackling the competitive market scenario across the manufacturing based industry is through continuous improvement of the techniques and approaches used to optimize the production process. Production process is one segment of the overall system for which the controlling and monitoring concern lies on the production scheduling and respective mechanism and/or tools used to schedule (da Silva et al., 2014). Therefore, the production scheduling contains the assignment and sequencing of the job order and operations, respectively and enhances the productivity of the flexible job shop manufacturing system.

In definition, production scheduling is allocation of all the required resources to convert raw-material/s that is/are fed into the production facility to be processed and then release final product/s which can meet and exceed customers' specification and expectation. It is one of the production performance monitoring mechanisms whereby the monitored output is evaluated and action based decisions facilitated for the improvement and/or optimization of the whole or given production problem(Peeters & van Ooijen, 2020; Soman et al., 2006). In this context, the adopted production strategy clearly affects the sensitivity of the scheduling problem as well as robustness/stability of the optimization of the process which can be attained through production scheduling.

Thenarasu et al.(2022) defined the job shop production as a type of production floor where mostly the customer based and/or highly customized job orders are entertained with the performance indicators such as lead-time, quality, price and quantity with high product cycle. Calleja & Pastor(2014) mentioned the shared fact that job shop scheduling problem has been extensively studied over the last few decades and it becomes the interest of the researchers as well as practitioners, equally; by definition, the job shop is production floor where 'M' machines are either stacked or single machine per workstation setting to execute a single operation on the incoming 'N' job orders based on the pre-defined process routings and respective scheduling set for the sequence. This is dedicated to minimizing or maximizing multiple measures of production performance metrics. This is the classical job shop set up yet the nature of the production floor type covered under this study has flexibility as an additional feature which makes it a harder combinatorial optimization problem.

On top of this, the nature of the operation changes as time rate and this set another feature of complexity to take over and indicates that well advanced and compatible scheduling is required to be developed in accordance; in this aspect of consideration, situation where the production type and respective strategy being implemented as a guideline to align the whole components of the system adds up to the complexity and degree of sensitivity of the production scheduling. In the case of the job shop production, production scheduling is both non deterministic polynomial mathematical computation as well as a combinatorial optimization problem (Xie et al., 2019a). In addition to this, the operation nature being dynamic and stochastic requires the production scheduling to be not only feasible rather also optimum to address the problem identified as maximum tardiness, makespan, mean flow time(Sharma & Jain, 2015).

However, most of the job shop production scheduling is constructed with static based rules and uses the reactive rescheduling strategy at the time of production disruption(Pierreval & Mebarki, 1997). Production scheduling is also the burning issue regarding the fact that most of the performance parameters of a manufacturing system revolves around this sub-system; it majorly concern with allocation of available production resources to tasks and select the best sequencing of the operations in accordance with the well-known constraints. Ramasesh (1990) the job shop scheduling problem is mostly characterized by a production floor where a number of jobs each containing one or more operations to be executed at in a specified sequence on specific machines and requiring certain period of time to be processed; thus, the potential objective of such study is to find and/or devise production processing order on the assigned machines for which a single or a set of performance metrics is/are optimized. Job shop is a production floor where a set of jobs are to be processed using the finite capacity of the production resources such as machine, operators, time, raw-material. Job shop manufacturing floor allows the production orders to move from one workstation to the other based on predefined route and/or sequence according to the machine assigned to process each operation (da Silva et al., 2014).

2.3 Flexible Job shop production

The flexible job shop is the extension of the classical job shop where the processing routings of the products have better flexibility to choose machines from while following the sequence set out for the operations. This helps to gain a better performance of the shop floor when the immediate machine is busy or overloaded or assigned to a prioritized job order operation(Calleja & Pastor, 2014;Chaudhry & Khan, 2016); still the characteristics of the classical job shop production scheduling mentioned and with slightly higher degree on the complexity is observed in scheduling the production process of flexible job shop production. Especially, when there is a wide variety of products. Based on the degree of the flexibility further classification of the flexible job shop scheduling (FJSS) is proposed by (Kacem et al., 2002) in terms of the degree of flexibility as: total and partial flexible job shop. Total flexible job shop scheduling (T-FJSS) is set-up where each operation can be processed on any of the available machines in the shop floor . Partial flexible job shop scheduling (P-FJSSP) is type of shop floor with less flexibility on the operations to be processed on any of the machines rather only on the selected few available machines. Fattahi & Fallahi, (2010) study revealed that the default setting of the FJSSP is exposed to a dynamic production floor where the flexibility feature used to handle it in a better way. The scheduling is developed as efficiently and stable as possible through defining multi-objectives for improvement and/or optimization. Therefore, considering more than one objective while developing scheduling of production floor yields more stable and efficient production scheduling. This can be more elaborated under this study for which the proposed production scheduling is based on multiple objective and it is generated by using the priority rules for production dispatching. Additionally, predefined conditions extracted by using knowledge based of the operators and production managers.

The study by Xie et al., (2019b) implies the complexity and significance of the study on the flexible job shop scheduling due to the fact that the current manufacturing trend is being highly influenced by the prospective advantage of the flexible feature. Particularly for the job shop based production processes. The additional features of the FJS is that the process routine of a given job order has the probability to have more than one defined route to complete the production process. As this feature increases the complexity in selecting the performance metrics to set as the objective for optimization and also the methods/techniques used to solve the production scheduling problem. As a result of this, different from the classical job shop scheduling (JSS) which majorly requires sequencing of operations on fixed machines. The FJSS deals with the assignment of machines for the operation to be processed on in addition to the sequencing of operation. Hence, the scheduling is comprised of two concerns: a routing sub-problem (selection of suitable machines among the available ones) and scheduling sub-problem (sequencing operations on the assigned machine) to obtain a feasible schedule that can optimize the predefined objective (Chaudhry & Khan, 2016).

Similarly, Amjad et al., (2018) raised a new conceptual understanding of FJSSP from the emerging factor which is the machine layout of the job shop: either it is set to be open where the processes aren't directed on one fixed path rather alternative route can be taken when the potential available machine is idle; furthermore, the applicability of route flexibility among the job orders for production differentiate the flexibility nature as total and partial.

In detail definition of the FJSSP, the single process plan for dispatched production order deals with operational and routing flexibility those representing the machine selection and operational sequence of a one-time process planning in which the rescheduling is set to be generated during occurrence of uncertain event (Doh et al., 2013). Due to this reason, the classical job shop is less hard than the FJSSP even to manage the unpredicted events in the production floor as it only focuses on sequencing the job order operations. The present study, considering the hybrid MTO-MTS production strategy simultaneously with no product differentiation or categorization of the products as standard and non-standard, the FJSSP added up with further complexity of the production floor yet helps to enhance the possibility of obtaining better quality solutions for each of the operational metrics set to be optimized.

2.3.1 Review on job shop and flexible job shop production scheduling

In addition to the routing flexibility, dynamic nature of job arrival and stochastic processing time make the scheduling problem more difficult particularly when the scope of the problem gets wider and complex based on the processing time stochasticity, due-date assignment practice, number of required operation of the job orders (as simple & complex components) (da Silva et al., 2014).

Since the process route of job shop production line defines flexibility features, flexible job shops require additional aspects to be considered when scheduling the production; it then consists of a decision to assign and sequence the operations on the machines available to carry out the production with optimized performance parameters. Blackstone et al., (1982) states the very basic fact that job shop production scheduling using dispatching rules even for small scale was very challenging as the system is mostly composed of queues across each workstations. Xie et al., (2019) the FJSSP turns to the classical JSP after the machine assignment sub-problem is handled. For this reason, the FJSSP can be treated using hierarchical approach where the two sub-problem are dealt sequentially. So far the concern of both classical and flexible job shop scheduling problem, studies have taken make-span as objective in optimizing. It is categorized as one of mostly used performance metrics/ key performance indicators of the production floor.

Based on the conducted survey by Ramasesh, (1990), the job shop scheduling problem classified based on the nature of the shop-production strategy as make to order and make to stock; nature of order arrival as static and dynamic; based on nature of processing time of orders as deterministic and stochastic; nature of processing environment as number of machines, variety of products, list of resource constraint and process routing; and lastly the methodology applied as analytical or simulation. Job shop scheduling problem is one of the most active research areas since the seventies and eighties. The majority of the study areas are composed of complex arrangements and a variety of products to manage under a single production floor and of predefined scheduling (Zahmani et al., 2015). In most cases the product variety, production floor type, type of production strategy implemented, machine arrangement and more are considered as null effects under the assumption of the production scheduling. However, these impacts the effectiveness and efficiency after the proposed solution is applied.

One major reason for the scheduling to be the most frequent focus of interest is due to the assumption made while dealing with the scheduling of the job shop floor. As a result of this, the proposed models often fail to yield the academic proven results. Some of the neglected conditions are buffer capacity, transportation time and distance, accumulation of WIP and the adopted production strategy implication on the overall operating and configuration of the production floor shop (Teymourifar et al., 2020). Various manufacturing systems have become to adopt more flexible manufacturing system setting where the uncertainty of the operational flow is quite vulnerable for market need fluctuation or unpredictable demand. This also comes along with extra customization on the products to be produced; thus, the FJSSP assumed to be the potential alternative to deal with the market/business sector dynamic behavioral change. Doh et al., (2013) study took this gap in the reconfigurable manufacturing system where the system of production scheduling can be adjusted using its hardware and software components for quick rescheduling using the alternative machines and sequence of the operation for each job order dispatched for production. In the review survey conducted by Chaudhry & Khan, (2016), the flexible job shop has come to the focus area of the production management based studies since the past two decades; in this survey majority of the coverage comes from journals and followed by conference papers. This implies the evolution of the subject matter in different manufacturing focused sectors and the production floor becoming the center of interest for different objectives that have been already optimized as both single-objective and/or multi-objective performance metrics.

In addition to this, the technological advancement of the machines and that of the production process monitoring and controlling techniques become one aspect of consideration in choosing the methods/techniques to use to schedule the production. As per the available research and respective findings in regard to job shop scheduling, it is one of the most difficult combinatorial optimization problem and the additional feature of the flexibility on the routing of the operations makes it more difficult than it was before; the first FJSSP is defined by Brucker and Schile in 1990. Thereafter, the research review survey conducted on FJSSP has revealed the growth and advancement of scheduling techniques used and respective objective functions defined (Chaudhry & Khan, 2016).

2.4 Hybrid MTO-MTS production strategy

In the production system, the implemented strategy is used as a tool of integrating all the potential contributing sub-systems in achieving the overall objective. In this sense, this strategy has the capacity to manage and create end-to-end synergy across every department. Peeters & van Ooijen, (2020) has developed taxonomic literature review mentioned that extensive studies being conducted on the implementation of make-to-order and make-to-stock type of strategies. As current trend, companies have begun to adopt these two strategies as mixed to take the advantage of each on a single production run. However, the concept of the hybrid production strategy has been found to be different across different literature; hence, the issue of production scheduling assessed from multiple perspectives and the proposed production optimization solutions have different implications. In the MTS based production system, customer order is provided from the stocked inventories of finished products while the MTO based production system is driven by the customer demand and products are delivered to customers directly shipped from the production floor. Initially, the production strategies active in implementation of both production and inventory are based on either order-production or make-to-order (MTO). For all incoming orders are directed to production and set for no finished goods buffer or stock-production. Or make-to-stock (MTS) case all incoming orders join the production line for finished goods buffer and the only order in the production line is entertained for the replenishment of the stock. Ciechanska & Szwed, (2020) assessed the one step further definition of hybrid MTO-MTS system in both the production and inventory cases; the MTO variants are assemble-to-order model (ATO), the engineer-to-order model (ETO) and the finish-to-order model (FTO); while the MTS variant are make-to-availability (MTA).

Table 4 Description and comparison of MTO and MYS production strategy

Feature	MTS	MTO
Goal	to maintain a certain amount of finished goods inventory	to fulfill a customer order within a specified time
Production planning approach	production is planned on the basis of demand forecast and inventory turnover	short-term planning is based on orders received, long term planning is based on sales plans
Start of production	production begins when inventory on hand drops below the minimum level	production begins when a customer order has been received
Product	standard, repeatable	bespoke-designed, bespoke-assembled, or bespoke-finished

Production volume	mostly mass,high-volume or medium volume production	mostly small-volume or one-off production
Industries and applications	FMCG,furniture,electronics and household appliances	machinery,construction,IT systems, exclusive products
Variants of manufacturing models	make-to-availability (MTA)	assemble-to-order (ATO),finish-to-order (FTO), engineering-to-order (ETO).

In striving to take over the ever dynamic market in almost all business sectors, the design and implementation of the strategy on which the system is set to run on or operates by has the potential to make significant change. Hence, companies based on their objective and respective approach to fulfill customers' requirement and expectation devises or adopt different types of production strategy. Paris & Voie, (2004) the additional and in-depth insight of applying the hybrid production strategy is for the sake of reducing the trade-off stress while maintaining the market competitiveness through systematic approach which deals the external and internal constraints.

The evolution of the hybrid production strategy at the conceptual and production setting definition can be traced from the consecutive researches and literature review compiled by (K. Hadj Youssef et al., 2018; Khaled Hadj Youssef et al., 2009; Paris & Voie, 2004); the very beginning is the condition where products assigned as stock and order products and treated according to the pure make-to-stock and make-to-order strategy as the time passes. Additional gaps become inevitable in which the setting transforms to a situation where the demand volume and stability started to be the criteria to categorize products as stock and order based production. Lastly, the setting of the production is defined as both by using the concept of common parts for every product variety and the stock production dedicated for the semi-finished products. The customer specification produced once the order is placed. This is done when a few more processes added to the previously stored semi- finished products. For instance, automotive, electronics and computer manufacturing and any assembly lines. As a result of this, the context began to swing with the make-to-availability and available to order instead of the make-to-stock and make-to-order respectively. However, the portion of common parts in the furniture manufacturing firm under the present study has lower degree of similarity in the parts; especially, the product variety is classified under product family type and respective member which requires different raw-material and definite adjustment on the set-up of the processing machinery. Therefore, the present study characterizes the pure and unambiguous context of the hybrid MTO-MTS production strategy relative to the previously used.

As stated by (Peeters & van Ooijen, 2020) the strategy that administers a given system can also be used to measure the key performance parameters. Theoretically, there are three types of production strategies from which a particular production based company selects from; although, the practical scenario reflects that most of them are engaged in a hybrid MTO-MTS type of strategy which is a combination of make-to-order and make-to-stock. The major reason to fall into this hybrid production strategy is to use the best of each individual production strategy- the MTO and MTS.

The individual production strategies- Make-to-Order and Make-to-Stock- have different performance metrics in a way to reflect the status of the production. Still with in depth observation of the applicability area of the strategies, it is possible to find interlinking performance metrics which are reciprocal in setting objectives to be optimized throughout the production system. (Fiems et al., 2020) mentioned the performance metrics of MTO as lead time of production, order delay and/or tardy job, maximum tardiness; while the MTS performance metrics are focused on work-in-process, frequency of stock-out condition, forecast accuracy and stock replenishment level. In definition, the MTO strategy, the production initiated when customer places an order either for standard products or customized while the MTS strategy based manufacturing is driven by demand-forecast from historical background of the market trend and/or predictive of the market natures using special clues. In both cases, production and inventory management and the information flow across the chain plays a vital role in extracting the best features of each strategy through perfect concealing of the drawbacks of each pure system (Fiems et al., 2020).

Production strategy and the nature of the production system highly governs the planning and control approaches to be used. As a result of this, the production strategy and production type alignment plays a big role in defining the objectives and respective key performance indicators (KPI) for the system to be improved. The context of hybrid MTO-MTS is defined and understood from different perspectives across the literature conducted so far and this has been detected as a gap both in the academic as well as practical terms of condition (Peeters & van Ooijen, 2020). Similarly, (JSSP algorithm) summarized the publications conducted with quite related concepts and it shows that hybrid MTO-MTS focused studies in the job shop production is limited to four in number while as strategy there are twelve publications. As concluded by (Ciechanska & Szwed, 2020), the acceptability of the MTA under the MTS model is larger than the usual MTS model trend considered in the manufacturing firms. This is due to the reason that carrying cost and cost of initiating the production are by far less than or absorbable compared to the customer's unfulfilled demand cost and also with the pressure. Similarly, the applied production strategy of the case under study MTS model variant resembles that of the MTA which implies that both MTO and MTS are being entertained simultaneously-parallel hybrid MTO-MTS production strategy.

So far, there isn’t a well-defined and stated definition and characteristics of hybrid MTO-MTS as system and due to this, various concepts generated and labeled as hybrid MTO-MTS without specific detail of the features and conditions required to be fulfilled to be called as one. In this sense, Peeters & van Ooijen, (2020) study stated three different conditions which can be defined or considered as hybrid MTO-MTS and these are sequential, parallel and floating.

- Sequential hybrid MTO-MTS production is where there are the two types of production strategy and their application is sequential in the production process control- which is basically the scheduling segment.
- Parallel hybrid MTO-MTS production is a type of hybrid production strategy where the MTO and MTS products process is entertained in parallel and simultaneously.
- Floating hybrid MTO-MTS production is the one that always carries over the MTO and/MTS production order implicitly so as to use the available resources to the max level hence the production floor never be idle unless a certain machine or resource issue takes place.

In any of the above mentioned settings of the production and contextual definition of the hybrid strategy, utilization rate and productivity enhancement is a given condition. This realized as a result of a high level of throughput achieved when the running production is set to be optimized using controlling policy and methods(Paris & Voie, 2004). In a similar sense to this study, the core of the present study can be taken from the role it has in exploiting the advantage of hybrid MTO-MTS production strategy. Mainly maximizing the reactivity to customer ordered products and management on the stock-out condition of stock ordered products.

So far conducted researches state, the recent fact in regard to the hybrid production strategy applicability. In the late 19th century, as a result of the need to manage the market and supply nature of existing manufacturing firms. The bare definition of hybrid given was the production proportion dividing into two sections where some portion of it is treated as stock while the remaining proportion is based on immediate order placement (Kalantari et al., 2011). Ofcourse, the potential benefit of the two individual strategies can be obtained in this hybrid system,however, with the condition of that being middle value for the benefits projected; majorly lower inventory cost and shorter delivery time. The reason that a hybrid production strategy has become the recent point of interest is due to the actual/real complexity arises while putting effort in exploiting the best/advantageous condition and optimization deemed parameters of the two extreme production strategies. The optimal selection of arriving orders to be dispatched for production has an important effect on a company's profit and market share. This leads to its own efficient production control-production scheduling. The production scheduling sensitivity comes from the resource constraints taking place in more frequent conditions in the hybrid production strategy; hence the appropriate production scheduling development is capable of improving the production performance parameter in scientific based optimization approaches.

Based on (Danilczuk et al., 2022) study, the majority of the hybrid MTO-MTS conceptual definition resembles the parallel hybrid MTO-MTS. This is where the product variety is quite limited on the most common production process before diverging to the customer and stock type of products. Even though there exists hybrid nature, it is the products production features defined as order and stock not the whole production process set up ready to entertain any product as labeled as both when the order is placed. Ofcourse, the manufacturing firms mostly found themselves focusing on optimizing -based problems whenever there was a challenge in competing the existing market and generating profit worth of the capacity investment imposed on it. Ellabban & Abdelmaguid, (2019) conducts study on the optimized production control policy for the fluorescent lamp manufacturing firm in order to manage the economic impact the firm is exposed to as a result of the energy consumption and utilization rate of the resources allocated. Production scheduling is one segment of the production control policy and can greatly impact the above mentioned challenges. Furthermore this shows the production scheduling decisions are the constituent block of the overall production system performance and respective interlinked subsystems of the manufacturing system.

Fiems et al., (2020) In the general sense, the strategy of a single sub-system most likely has the chance to affect the other subsystems that are linked horizontally as well as vertically. The concept of hybrid MTO-MTS strategy majorly applied to manage the work-in flow of a system with monitoring and control aspect once the plan set out. Th plan can be implemented using the strategy defined to be enact by managers; hence this hybrid strategy applied to the inventory management as well as production control section of a system as per the desired objective improvement purpose outlined. According to the production control which is also linked with the inventory level, quality standard and waste minimization. Consecutive studies of (K. Hadj Youssef et al., 2018; Khaled Hadj Youssef et al., 2009; Paris & Voie, 2004) conducted study on the argumentative point raised in the application of hybrid MTO-MTS production strategy system and decision procedure. The argumentative issue is as to whether and when to interrupt the production of the MTS item in order to produce MTO item job order; considering the inventory cost and customer-lead time as performance indicator to evaluate the applicability of the hybrid production strategy in the predefined production setting which is using global performance of the mixed policy. The very basic thesis of this study comes from the gap of conceptual understanding and definition of the hybrid production strategy and limited focus on the production floor type and related features along with the processing routes flexibility.

2.4.1 Hybrid MTO-MTS production strategy in flexible and/or job shop

The need to couple the advantages of the individual production strategy has been recognized as the best alternative considering the products and process arrangement of a given production floor shop(Fiems et al., 2020). Adan & Van Der Wal, (1998) conducted research study to emphasize the advantage of combining the make-to-order and stock strategies in inventory as well as production control aspect using two models; the first model has representation of sequential hybrid production strategy where the inventory stock level reaches to maximum level the production floor becomes available to produce the make to order job order or vice versa. The second model has representation of the float hybrid production strategy where the production process has segmented to two section yet both the stock and order based products have common production process. Here the stock is more of semi-finished products and the order based production process takes over from the remaining production process nevertheless of the prioritization concern between the stock and order production.

In both cases, the production lead time reduced significantly when compared to the pure strategy in either of the strategies. In dealing with one degree complexity from the classic production type, an additional concept comes to the focus area- order acceptance and rejection. Then these majorly depend on the production scheduling in practice for that hybrid MTO-MTS production strategy based production floor. The Kalantari et al., (2011) study identified this as gap and proposed a novel decision support system for order acceptance/rejection in five steps: the step begins with customer prioritization and ends at the production scheduling of the job orders that are accepted. It is based on the necessary information extracted from raw-material supply capacity and corresponding condition of the production floor. Mixed integer mathematical programming model to determine the price and delivery date.

As mentioned in the evolution of the hybrid production contextual as well as production setting, product differentiation is one version of combining the two pure strategies-MTO and MTS. This version of the hybrid production strategy is preferred to minimize the inventory cost as the items to be stocked have a better chance of becoming the order to produce based products. (Gupta & Benjaafar, 2004) study focused on the conditions to analyze the model of this combined system and optimize the performance indicators as a result of differentiation type of hybridization in the case of lead times are load dependent. A mathematical model, analysis and numerical examples applied to demonstrate the preference of the delayed differentiation- congestion due to tighter capacity- and inventory buffer to manage were used as indicating factors of the utilization as well as stability of the imposed strategy.

Based on (Kaban et al., 2012)study, new insight of hybrid production strategy which are to determine sensitive concerns and key performance indicators of the production emerges from the production rounded activity-planning and scheduling. And also from marketing characteristics framed in customer behavior and availability of the item rather than the demand captured at that time of moment.

Commonly, the production floor which adopts the hybrid production strategy by default sets priority for the customer/order to produce products and this approach is vastly practiced on the previously conducted research (Adan & Van Der Wal, 1998; Kalantari et al., 2011; Kuthambalayan & Bera, 2020). However, this set limitations on the scope and definition of the hybrid production strategy in the production system, especially the job shop type (Beemsterboer et al., 2017). As a result of this, the proposed solution is recorded to be sub-optimal and the need to pursue a study fully dedicated to entertain the two pure strategies as one with their respective performance parameters. Therefore, the hybrid production system and its controlling system can be evaluated clearly. In the study conducted by (Beemsterboer et al., 2017)significant indications mentioned that there is need to take into account developing planning policy majorly dedicated for hybrid production as per the definition stated for the concept of the hybrid.

The need to have this study can correlate with the fact that the MTS based orders join the production either of the two condition: work starvation takes place on one of the available resource and to keep them busy or when the MTO orders have tight due date and the orders from stock failed to reduce the sales loss- the MTS order continue once the MTO orders left the production line. Getachew & Berhan, (2015) recent trends of manufacturing companies focus on risk of failure to deliver an order as both earlier and late completion time. This in a way affects the inventory carrying cost and penalty of tardy job orders. For this reason and other optimization objectives, the hybrid MTO-MTS production has become more adaptable in the real production environment. Therefore, this additional feature of the production practice requires to be considered in production scheduling/sequencing strategy and tools or approach used.

2.5 Methods/Techniques and tools in production scheduling

With the concept of the need to use dispatching rule (DR) based on the dynamic aspect of factors mostly considered, the comparison of that specific shop floor scheduling using different DR by changing the prioritized performance metrics handled using a simulation tool. This tool can model the characteristics of the shop floor operational aspects and conditions in applying well-fitted DR corresponding to the optimized objective and compare the scenarios developed to select the best performing DR. In addition to this, the dispatching rules greatly depend on the configuration of the system, practice or conditions of the operation and the performance criterion used to evaluate the DR. As for the case of heuristics based methods of production scheduling, the dispatching rules are the most frequently used method for the simplified nature in ease of use and also integration with a simulation tool. This tool is used to capture, model and run the real production floor with a set of controlling and/or performance measurement parameters (Turker et al., 2019).

In conducting simulation-based job shop scheduling focused survey by (Ramasesh, 1990), the considerations that are taken as factors to affect the simulation model of the job shop floor are: probabilistic distribution type of arrival time, order release pattern assumption as it might be instantaneous or scheduled release to production, processing time probabilistic distribution. Ofcourse, the fact that the probabilistic distribution variation directly affects the dispatching rules to be experimented on as well as developed from according to the performance criteria. Therefore, the output analysis and performance criteria directly impact the simulation model based study of scheduling problems as a result of the DR used (Ramasesh, 1990).

2.5.1 Job shop production scheduling

In the production scheduling of a given job shop production floor, most of the assignment and sequencing rules use the well-known dispatching rules with clear customization for the type of production floor under study(Raghu & Rajendran, 1993). Still, there is no right dispatching rules across the common criteria defined based on the production performance indicators. Moreover, the dispatching rules are sensitive for features that aren't quite related with the non-functional concerns of the production floor such as layout of the machines. In a similar concept, the dispatching rules are also influenced by the production strategy developed to manage the production overall nature.

Based on the information considered, devising the dispatching rules can affect the capacity of the DR performance in achieving the desired optimum value of the criteria; thus, the dispatching rules generated from combining two or more information of the production floor scores better value(Raghu & Rajendran, 1993). Corresponding to this, the overall production floor status which is basically exposed to change as time rate (dynamic in nature), the rules to apply in scheduling are required to be evaluated as a function of the workload and time constraint. As the research on job shop scheduling becomes more detailed, the problem becomes computationally intensive to solve. This leads the researchers to focus their effort in selecting approximate algorithm such as heuristic algorithm based DR which is capable of resulting near-optimal solution at reasonable time and better quality of solution and potentially it becomes relatively robust to real-word environment dynamism (Calleja & Pastor, 2014). Zahmani et al. (2015) study claimed the application of multiple DR for each workstation/machine based on the optimization objective of the study which is the makespan. This helps for construction of databases on scheduling problems and respective effective DR sets to use for as per the optimization objective parameter. The study also propose database composed of several job shop problems and their best corresponding DR. Finally the data will be mined to develop a decision support system that can decide the best DR to use on a machine for a new JSSP. It can be used to reduce time of response and increases effectiveness for dynamic scheduling needs of the production floor.

Calleja & Pastor, (2014)concoct the definition of dispatching rules from list of literatures where the application of DR proved to be the best one in improving the performance measure of the job shop scheduling problem; dispatching rules are combinations of heuristic and priority rules each containing more than one. Therefore, priority value is given to jobs when sequencing their operations and the heuristics rule applied in managing the criteria and optimized objective alignment based on the priority value set in that scheduling scenario. Related to this concept, the present study adopted the heuristic algorithm based dispatching rules -with immense applicability degree in dealing with complicated, dynamic and wide scheduling problems in practical production set up. DR is selected as they are easily implemented and efficient in order review and release section as well as sequencing of operation in the production floor. Ortíz et al., (2018) emphasize that production scheduling as one of the critical issues in the planning and management of manufacturing process and job shop type of production floor case of scheduling has intensified the nature of searching for problem solving.

2.5.2 Flexible job shop production scheduling

Based on the literature review conducted, the attention towards the flexible type of job shop production has received an increasing attention, especially in the academics aspect of the studies.

As a result of this, the complexity and significance of the subject matter led to the application of different methods and techniques to develop production scheduling. The study (Xie et al., 2019b) categorizes the methods and/or techniques used as exact algorithms, heuristics and meta-heuristics. This classification gives the opportunity to use multiple and combined methods to solve flexible job shop (FJS) scheduling problem setting and measuring either reciprocal or non-complementary performance parameters of the production floor. The exact algorithm mainly focused on using mathematical formulas such as linear or mixed integer programming based models (Xie et al., 2019a).

Applicability of simulation has become revised in recent researches and mostly used in an integrated mechanism with recently emerged methods. The effect of scheduling rules in dynamic flexible job shop are difficult to evaluate by means of analytical technique and for this reason simulation addressed this issue by representing the real production system in modeling. A wide variety of DR examined and identification of effective rules for each situation/scenarios(Vinod & Sridharan, 2009). In the last few decades, the applicability of dispatching rules in dynamic scheduling of a given production has increased and also its simplicity and ease to model conditions in simulation models. They can be very simple as well as complex based on the attribute sensitivity degree and number of objective and/or target performance metrics to be improved (Pierreval & Mebarki, 1997). In the application of the simulation, certain parameters are considered which can give better representation of the operating environment based on the job arrival, type of production, size of the shop floor, order release and machine maintenance strategy. As a result of this, the objectives to meet and parameters to consider in developing objectives become more flexible and representative of the system under consideration (Blackstone et al., 1982).

With the concept of the dispatching rules, the due date setting needs to be considered to be inclusive of how the due dates are set as well as its relationship with the overall nature of the job shop in regard to the decision making strategy or path-way. Hence, the due-dates can be exogenous or endogenous as for make to order and stock respectively. The inference by(Ramasesh, 1990), implies the fact that the dispatching rules are reflection of the strategies to use based on the internal status and prioritized value of the production floor at that given time. This leads to the conclusion that it is a must to have a combined dispatching rules specifically customized for the shop floor features for which it becomes/show sensitive character towards a direct implication of the strategy adopted in the production floor control such as scheduling.

As mentioned in the consolidated survey of researches conducted by (Chaudhry & Khan, 2016) regarding the FJSSP, the applied techniques to solve the scheduling problem ranges from mathematical to various metaheuristics such as mathematical programing, evolutionary algorithms, ant colony optimization, linear/integer programing, tabu search, heuristic and so on. Due to the usual trend in order to extract advantage of different techniques through hybridization, the FJSSP also applied hybrid based techniques and this took up to 35% of the review research. A total of 191 journal articles in which there are 197 applications of similar techniques. Tanev et al., (2004) conducted a study to improve business response speed for the total flexible type of job shop production floor. The study area is composed of plastic injection machines with different type of molds, products and one-to-many based relation of machines with both the mold and products. The proposed solution is through web-based online customer order placement and status follow up of the assumed due date. The study applied a hybrid evolutionary algorithm with priority dispatching rules to schedule the different customer orders in order to attain lower level of tardy jobs and time of delay. The need to combine these two approaches is to exploit the advantage and cancel out the individual methods' draw-back in scheduling the different products on the available mold and machine to be processed on.

(Kacem et al., 2002) mentioned the application of the dispatching rule to develop the algorithm of localization through which the machine assignment is determined among the available machine set in both cases; however, the partial flexible type of production floor happened to be exposed to higher degree of difficulty in addition to the classical feature of job shop production scheduling problem. As the current trend of the scheduling in job shop production floor -where the expertise is to give variety of products with different process routing and time- the genetic algorithm is used to generate the most feasible and optimum sequencing/scheduling set by using the dispatching rules in a combined form (aka hyper-heuristic). This can be used for the real-world production complexity to minimize the completion time (Kacem et al., 2002). Chaudhry & Khan, (2016) As dealt by previous studies, the FJSSP requires a heuristic based approach instead of the exact algorithm based approach to solve scheduling caused problems with a list of conditions to consider such as product variety, machine layout and arrangement, flexibility degree and more. In the case of (Thenarasu et al., 2022b)study, rules to assign machine and sequence operations have developed and each incoming job order passes in these rules taking the most optimum schedule flow among the feasible alternatives in consideration of the selected operational performance metrics as to be optimized objectives.

Moreover, the flexible job shop scheduling is quite representative of the real-world production environment/system in which the dynamic and multi-objectivity of the production nature indicates the fact that academic studies need to address the gap between the theoretical and practical knowledge through such research study(Ortíz et al., 2018)

Of Course, the evolutionary algorithm is the most widely used method/technique in the FJSSP as individual and also combined with other potential techniques based on the selected objective and production nature; genetic algorithm is the first and most applicable in solving FJSSP. In the content assessment of the researches and respective methods/techniques used, the study area is focused on developing new research based on benchmark comparison whenever adjustment is imposed on the research content.

Due to this fact, the hybrid and evolutionary algorithm techniques becoming the insight while others such as heuristics and mathematical models or miscellaneous techniques began to be left out; in this sense, the proposed study selected to use heuristic-DR and a discrete event a simulation tool to deal with the multi-objective optimization FJSSP. (Morinaga et al., 2017) implies that the need to use dispatching rules as an input for the genetic algorithm -prompt to create population from- as the rules are used to determine the selection and sequencing of the machines and operations to be processed on, respectively. This provides the chance to develop criteria based on the performance indicators which are set as optimized objectives.

2.6 Application of Dispatching rules and Simulation for production scheduling; JSSP and FJSSP

2.6.1 Dispatching rules

Ramasesh, (1990) and Sharma & Jain, (2015) defines dispatching rule as a procedure used to determine the ranking order of jobs and respective operation on available machines and optimum sequence of the required operations. Dispatching rule also known as priority rules used to prioritize job orders in assigning as well as sequencing operations on the constrained resources of production. Depending on the production floor type and the need to be flexible with the time rate, dispatching rules can be either static or dynamic.

At the early stage of dispatching rules application, the major focus was minimizing inventory cost for the manufacturing firm. As the performance indicator indexes began to increase the consideration of using dispatching rules, the applicability ranges from optimum utilization of production resources to intangible aspect of production output. These are customer satisfaction, quality assurance and competitive advantage of the market for the manufacturing firm. In parallel to this, the dispatching rules have been classified in categories based on the concerns set on for improvement or reference linked with the objective set that are defined when stating production scheduling problems(da Silva et al., 2014; Turker et al., 2019).

According to the objectives to be optimized, the category of these rules is determined as processing time, arrival time/delivery time, work content, machine requirement and work load or queue(Peeters & van Ooijen, 2020; Sharma & Jain, 2015).Chang et al., (1996)depending on the critical information considered in defining the rule, dispatching rules are categorized under four sections and these are: process time, due date, combination of two and others (customized based information incorporated to develop rule) (Holthaus & Rajendran, 1997). This information can be universally known or specific to that case under study as a result of the product variety range, production volume, process layout, maintenance and also production strategy adopted in managing the competitive market advantage. Of Course, these rules are used based on the performance indexes set that refer to the objectives defined in solving the problem caused by production scheduling. Most frequently used performance indexes are makespan, tardiness, work in process and number of tardy jobs.

(Zahmani et al., 2015) study emphasizes the concept of using different DRs across different machines for better performance of the production floor as a whole while setting common objectives for optimization. Dispatching rules are one of the approximate algorithms with better compatibility to absorb the complexity degree of job shop scheduling problems.(Turker et al., 2019) defines the dispatching rules as procedures devised to provide the best feasible as well as optimized solution to complex problems taking place in real production scenarios. In the condition where the optimal solution to be derived from heuristics-DRs-the very basic aim of the method is to define priority for each job on each machine queues extremely quickly which strengthens the responsiveness of the system whenever there is change on the operation of the production.

The knowledge based DRs required to change according to the production floor shop characteristics and the desired objectives over multiple performance criteria so that the limitation of the DRs improved and its respective applicability with immense flexibility (Hübl et al., 2013; Pierreval & Mebarki, 1997). In this sense, the combined DRs are aimed to achieve objectives according to the prioritization value yet required to be optimized simultaneously with slight degree difference. The consideration of the operating condition can be used as an input in deciding the prioritization rank of the performance criteria.

As discussed by (Pierreval & Mebarki, 1997), the proposed dispatching rules are customized for the flexible job shop with hybrid production strategy as its operating condition- which is to be considered under the present study- the combination of the DRs and respective selection can be designed using the active symptoms and conditional prioritized value for a given performance metrics defined in the objective. Similarly, the simulation model represent the selection of the DR according to this guideline proposed as follows:

Step 1*: Detection of active symptoms*

In this section, the overall status of the operating status is assessed based on the objectives to be optimized and respective changes taking place at that time or predicted to do so; and then potential DRs provided to manage the active symptom of the system.

***Step 2**: Choice of the DRs to use*

Here, the DRs to use are chosen from the pre-defined DRs-mostly combined-using if then conditions for the list of performance metrics prioritized value rank as primary, secondary and tertiary.

In similar consideration with other studies in the application of the dispatching rules to select job orders for operation on available machines, the rules are classified as machine selection rules and operation sequencing rules for the list of available alternatives of machine and sequence for that specific job order (Doh et al., 2013). In the case of the job shop production type, the dispatching rules arise from two major attention points which are the criteria sources; these are rules based on the job order, rules based on the job shop production and rules based on the hybrid of the two.

- Rules based on the job order focuses on the attribute of the job order such as delivery date, order sources, arrival time pattern, variety of products and volume of production
- Rules based on the job shop focused on the condition and/or current status of the production floor and respective machines with reference to the job orders or operation to assign or sequence respectively.
- Hybrid rules are the combination of the dispatching rules of the above two and better capacity to incorporate the multi-objective criteria and performance parameters.

The purpose of dispatching rules is to devise the rules with supplement effect of the criteria stated to improve the selected performance parameters. In the global level of consideration, there is no defined dispatching rule that performs better than all the others. Moreover, the performance of DR varies as a result of time and respective operating conditions of the production floor which makes the heuristics more applicable in almost every industry sector yet with a list of features to be considered in selecting the very few key performance indicator parameters plus the integrability with other approaches and tools (Pierreval & Mebarki, 1997).

Zahmani et al., (2015) elaborated the condition in which the DR used as method to schedule job shop production integrated with the other heuristic, meta-heuristic to enhance the optimization level of the targeted objective and/or performance measures. In this sense, the priority rule approach gives the chance to include multiple objective functions which can directly or indirectly impact the production efficiency evaluated through selected performance measurements. The literature review compiled by (Xie et al., 2019b) indicated that the practical FJSSP performs better using the dispatching rules compared to swarm intelligence algorithm; this emphasizes the significance of the present study and respective methodology to solve the FJSSP of real-world furniture manufacturing with hybrid MTO-MTS production strategy. The dispatching rules based on priority criteria used to address the multi-objective function of flexible job shop by using combination of the priority rules in accordance to the criteria set forth for optimization such as: minimization of the makespan, total flow time, mean tardiness, the number of tardy jobs and maximum tardiness(Doh et al., 2013).

These dispatching rules have gotten the better preference over other heuristic algorithm based methods due to the features they have and its polynomial time complexity. In parallel to this, the application of DR and respective scheduling environments along with the objective function defined can change the result obtained and this can be taken as a reason for the continuous extraction of dispatching rules in almost all similar research problems which revolves around the job shop production scheduling problem. Using expert experience can also be used as a way to construct DRs and then combine them linearly or nonlinearly with the important features of the scheduling environment (Teymourifar et al., 2020).

2.6.2 Simulation

Designing manufacturing as a system requires a widened view of each sub-systems and their potential effect on the performance of one on another as well as on the overall system performance metrics. Hence, production can be taken as the most affecting sub-systems in terms of its management and controlling mechanisms(Rad et al., 2014). Simulations are in fact the modeling and representation of the system with the aim of determining the real operational behavior of that system. As technological advancement adversely changed from time to time, computerized simulations began to be applied to model and properly analyze the functions of systems, particularly production floor based systems. Turker et al., (2019) mentioned that the simulation as a tool can be a support system to evaluate the effectiveness of the dispatching rules and respective criteria defined before proceeding with the decision making process. Therefore, it is mostly used to analyze the system from desired point of view and select improvement areas of the production system. Since every detail of any system can't be modeled, certain assumptions have been developed to manipulate the functional section of the system while directing to the objectives set to be optimized.

Similarly, the details of the production floor operating in a real environment can be omitted by defining logical operational assumptions and in accordance with the scope of the study. Pierreval & Mebarki, (1997)research study magnifies the need to use the simulation tool in optimizing the performance metrics of production scheduling and also in selecting the best performing DR by using the optimization technique of simulation. The very basic need to use the simulation is to handle the off-line calibration and application of the heuristic on-line while the production floor is operating.

In common with other job shop production scheduling studies, the application of simulation has been a very practical tool to measure and define the effectiveness of potential/feasible dispatching rules (Raghu & Rajendran, 1993). In the job shop scheduling problem, the application of DR in tackling the dynamic nature of the production floor shop can be visualized using simulation model as tool and evaluate the performance of the proposed DR and also observe the system reaction to mitigate production perturbation risks caused by arrival of new jobs, machine break-down, raw-material starvation and more (Zahmani et al., 2015). As a result of this, any disorders and dis-functioning components of the system can be traced and suitable solutions for the system proposed accordingly (Rad et al., 2014).

Based on the literature reviewed, frequent application of simulation tools for the manufacturing arise from the capacity to solve problems with stochastic nature and its flexibility to integrate with other optimization algorithms(Liu et al., 2018). As with the recent technology dynamism, the industrial development requires to be modeled and represented with real-world scale of problem by coupling simulation with different algorithms and techniques to propose new variations of existing algorithms.

In addition to the representation of the existing system through conceptual and computational models, the simulation tool increases the quality of getting the most optimized solution or scheduling approach for the case under study. Similar to (Rad et al., 2014) study, the application of simulation as a tool is to select the optimum scheduling rules among the proposed alternatives in order to minimize or maximize the decision-making criteria for the stable production scheduling method of the FJSSP with hybrid MTO-MTS production strategy.

The need to pass appropriate decisions is the basic necessity observed in the system where the strategy is hybrid. Production scheduling being one of the controlling tools of production, its corresponding appropriateness level has the power to tweak every performance metrics of the production. The simulation as a tool applied to clearly model and represent a given system and those changes recorded as a result of controlling policy imposed in (Ellabban & Abdelmaguid, 2019) study. According to this notion, the application of Arena simulation as an analyzer tool as a comparison and scientific based decision making support system in the present study-the hybrid production strategy - is quite preferable over the two pure strategies. In addition to this, the simulation tool allows to represent the production model in different major section where the proposed decision-making aspect is being considered.

(Ellabban & Abdelmaguid, 2019), the present study can depict the production scheduling based problem as information/ paper-workflow and production-flow where each representing the control as order acceptance and selection and specific assignment and sequencing respectively. Also a study of (Rad et al., 2014) compiled literature review implies the fact that the simulation techniques and their efficiency in manufacturing departments, particularly to the scheduling and other production process controlling techniques. The construction of simulation as tool incorporates problem definition, data collection, model development, acceptance and confirmation of the model authenticity and finally running the model. Due to this content of the tool, the real operational scenario can be captured and respective solution alternatives proposed based on a set of analysis and selection of the best among them(Rad et al., 2014).

2.6.3 Related works

(Ramasesh, 1990) study presented as a survey of literature based on the simulation as a tool used for modeling & analysis of production floor performance metrics. Inference regarding the variation of the results of research studies comes from the factors in consideration of affecting the job shop scheduling and details of the model presented.

Basically, industries become inefficient due to the fact that scheduling is associated with different production management tools which are majorly integrated into an advanced planning system. As a result of this, a specific and particular study on the scheduling and techniques becomes the focus point of studies. This is due to the need to mitigate both financial as well as operational risk of the manufacturing firms (Zahmani et al., 2015). (Doh et al., 2013) selected production floors that exhibit the flexible job shop and the scheduling problem is addressed using priority rules which can provide feasible machine selection and operation sequencing solutions simultaneously. The result of the priority rule was analyzed by using a simulation tool and it concluded that the shortest processing time works the best for all the performance metrics set out as an objective of optimization.

(da Silva et al., 2014) study used simulation to evaluate the sequencing of operation in a given job shop production based on the dispatching rules devised in such a way that job order arrival set as dynamic with the stochastic process time. Hence, it give more appropriate real production environment as the complexity of the scheduling problem arises from this aspect or condition. Moreover, the objectives set to be optimized- mostly multi-objective- measured and improved in accordance to the effect on the production key performance indicators listed. Ramasesh, (1990) states that although the production scheduling of job shop floor has been under continuous scientific study, the need to have clear path of the issue and respective trends along these years initiated to conduct survey of similar researches from the following two points of view: job shop simulation modeling and experimental considerations with different approaches. This has taken so far and provided the ultimate findings of the studies regarding the job shop performance criteria of interest.

Beemsterboer et al., (2017) study uses the simulation as a representing and sensitivity analysis experimenting tool to support the proposed integrating methods/approach of the MTS item on the MTO based job shop production floor. The simulation is executed by using python based software known as SimPy and compared the proposed integration approaches setting the reference as 0%

MTS sales lost and MTO tardy jobs. Ortíz et al., (2018) elaborates the complexity phase of the flexible job shop scheduling problem as a result of the need to incorporate assignment and sequencing of operation set for production. As with the detail definition provided on scheduling concept, scheduling is the task of production management that focuses on determining which machine/resource can process the given job order and also which job order operation can be performed at a given time of period. More frequent challenge in dealing with the flexible job shop scheduling is to improve the production efficiency, especially proper and advanced management of machine maintenance (Ortíz et al., 2018). In addition to this, the scope of scheduling under dynamic operating conditions have become the academic focal point.

The applicability of such flexible job production nature is increasing in almost every manufacturing sector for better business performance metrics value and improvement meanwhile dedicating to customer requirement and even more to their expectation. As the changes in the production floor become inevitable due to many reasons to mention for the customer/market demand customization takes the majority of the issue. The DR began to develop as to represent a particular case study production floor features and assumption. But, still the production section assumed to be static while modeled and this became the gap identified between the academic and practical format of the case studied. Thus, application of knowledge and experience based reference in designing DR and integrated with well-defined conditions of the system. This enhances to develop the most appropriate DR and dynamically select a combination of the DRs from to attain the objectives optimization. In order to identify the optimum combination among the feasible DR combination, the simulation is used to compare and analyze the experimental output respective of the stated or selected performance metrics improvement (Pierreval & Mebarki, 1997).

As one of the output of the academics studies, the production strategy has designed to be categorized under one of the common the production strategies as make-to-order, make-to-stock and hybrid MTO-MTS; thus based on the marketing, inventory, supply-chain, production type and layout, machineries nature and more factors to mention the manufacturing firms tend to choose one of the production strategy to use. Manufacturing companies based on the large volume of production, stable demand, perishability nature of the product, high set-up/change-over time cost, frequent machine failure prefer the make-to-stock production strategy while manufacturing firms with exact opposite nature and/or operating condition most probably tend to adapt the make-to-order.

Hybrid production strategy requires to consider the following points: production capacity stability, market stability and customer demand behavior and these considerations can be represented by using simulation (Köber & Heinecke, 2012). Upon the literature review compiled by (Kuthambalayan & Bera, 2020) on previous and recent studies in regard to the mixed/hybrid MTO-MTS, the frame-work depicts the interaction/linkage of the concerns combined as to the reason why the hybrid MTO-MTS is preferred over the other strategies. Even when there are conditions of high product variety yet same resource/facility being used, delivery time sensitivity for MTO products and inventory management policy for MTS products being handled with opportunity to improve all over the production floor. Therefore a compataible applicability in real-world production environment. This signals the need to develop a compatible method and approach in implementation of the hybrid MTO-MTS production strategy is mandatory and it is capable of providing opportunities to get the best out of the combined production strategy in dealing with flexible and responsive features of product variety production.

2.7 Summary of literature and gaps

Job shop scheduling as general is labeled as NP-hard combinatorial optimization problem and in the case of the flexible job shop, the complexity and sensitivity degree increases to make the problem further difficult to solve. However, it has been the burning issue both for the academician as well as production managers for the last three decades. This is due to the fact that the dynamic market nature forces most of the manufacturing industries towards customized products and also volatile and seasonal demand nature. As a result of this, the efficiency and quality of the system has become majorly relying on the production department- on the monitoring and controlling aspect of it-in particular production scheduling.

The production scheduling of the company is handled manually and lacks consistency which makes the performance metrics to be affected every now and then whenever there are dynamic and random events. Consequently, the targeted objective functions are always at risk and complexity to solve the problem escalates (Calleja & Pastor, 2014). Production scheduling is a control mechanism to maintain the optimum performance of the production system as a sub-system as well as the manufacturing system as whole through the concept of horizontal and vertical integration.

Despite the fact that in the last two to three decades production scheduling based works have been conducted, simulation model development has not been a key focus area in representing the production floor with less assumption to mimic the operating production system (da Silva et al., 2014). Literature survey of the state of the art depicts the finding that simulation efficiency in manufacturing related departments; in particular to the scheduling and other production controlling techniques. Similarly, the production strategy has not been considered in model development and respective dispatching rules to use in the dynamic production set-up. In addition to the concept derived from (Pierreval & Mebarki, 1997), the present study of the job shop is built on the capacity to entertain stock and customer based orders on the wide variety of products and oftentimes tight due-dates.

The need to have dynamic dispatching rules whenever there exists changes such as random/rush job order arrival, extension or expedited of job order due date, change of prioritized value of performance parameter/metrics takes place over time. Therefore, the hybrid flexible job shop scheduling highly requires continuous update on the scheduling rules as well as the criteria to prioritize while selecting job orders to dispatch and sequence on the production floor and on a machine. The hybrid production strategy gives flexibility to entertain high product variety and quick response time, conflicting objectives in relatively easier and optimal conditions if the production scheduling is designed as per the desired performance optimization.

The basic application pattern of the dispatching rules in the case of production scheduling is more or less the same except the fact that the objective set for optimization as performance indicator metrics changes and the category of the DR focused on selected interest areas. The simplicity and flexibility of the heuristic enabled most scheduling problems to adopt it. The need to incorporate knowledge and experience based rules is yet at an early stage. The two very basic gaps identified in conducting literature review with the key words such as production scheduling, job shop, dispatching rule, hybrid production strategy and simulation.

Moreover, the concept and definition of hybrid MTO-MTS production strategy and the consideration of the implemented production strategy in devising production scheduling. Majority of the flexible job shop scheduling problem and respective techniques applied have focused and entertained the problem with single product type and/or similar product types through the first few processes and stock as semi-finished products. As a result of this, product variety and conceptual definition of the hybrid MTO-MTS production strategy induces new aspects of research. In addition to this, the techniques/methods and tools reflect limitations in the case under study; for instance, most of the performance indicators for the job shop scheduling with either of the flexibility types are completion time, mean flow time, maximum and average tardiness. However, the throughput and WIP accumulation percentage also needs to be taken as a key performance indicator of the production from diversified aspects and solutions to provide. Hence, the dispatching rules have not been assessed from this aspect in the reviewed literature so far. Similarly, configuration of DR to the active operational production floor (Alvarez-Valdes et al., 2005).

Lastly, the gap identified is that the lack of input for the dispatching rule and further methodology practice in this particular study area by taking into account a well-developed database. The database which is composed of several hybridized production strategies on the flexible job shop setting, variety of products and randomness of job order arrival, dynamic and stochastic processing time focused job shop problems. Extracting a few reliable and effective DR and inclusive of other issues to solve through the production scheduling. As the aim is multi-objective, the prioritized value of the complementary performance metrics changes along with the operating condition and production floor status-mainly focus WIP accumulation percentage and maximization of throughput in addition to the number of tardy jobs and completion time.

Chapter 3
Research Methodology

3.1 Data source and collection

The study uses both primary and secondary sources to collect data from by using different data collection tools and techniques. The data collected using these two sources are used to devise dispatching rules and simulate the system through a model. Also the data used to validate and verify the modeled system that is built by using simulation software. Moreover, these data are targeted to thoroughly understand unwritten practice on the production floor, devise customized dispatching rules and in-depth insight of the case under study enough to propose a solution with proven improvement value.

3.1.1 Primary Data

Deluxe Furniture production layout is designed in a way processing route flexibility used to reduce the resource conflict among the 107 product varieties to be processed on the available five machines. The primary data sources are direct observation of the overall production operation, informal interviews with responsible staff of the production department such as machine operators, line supervisor. It also included a marketing and sales manager. Finally focus group discussion conducted to get clarification and in-depth explanation on the conflicting terms and understanding of the production floor proactive as whole. The details on the collected data type and respective significance in the study- in terms of providing insight on the proposed solution is described as follows:

- **Direct observation**

It is conducted to verify that there exists a sensitive need to focus. These issues are the WIP accumulation percentage as a result of the production scheduling. The direct observation is used to understand the focus area clearly based on the day-to-day activity routine and its impact both on the throughput and maximum tardy number of a given job order set. It also gives a highlight of how the information flow is and how it handles the dynamic nature of the operation, and the degree of consistency on decision making for similar scenarios taking place. This direct observation is used as an input to design the discussion points and define the problem statement in a more precise way as it aligns with the reviewed articles and selected approach to propose the solution to improve the production performance metrics. By using time stop, the processing and set up time of each product on each machine is recorded and incorporated in coding the validated model-computational model development.

- **Informal interview is conducted**

The majority of the informal interview is conducted with the direct machine operators, production line supervisor and manager and marketing and sales manager in order to:

1. differentiate the products
2. understand nature of the market across each product
3. identify the most frequent products and respective product family category
4. understand how the production job order is processed after order is placed either by customer and/or stock
5. clarify the actively used dispatching rules and respective scenarios.
6. visualize the order placement and sorting is handled before transferred to the production department.

- **Focus Group Discussions**

In this study, the focus group discussion is held for two rounds of session due to lack of well recorded documents from the production department and also detected conceptual gaps in understanding the same concept while carrying out informal interviews. This triggered the need to use focus group discussion among the potential participants throughout the production.

The reason to hold two rounds of sessions is due to the fact that the participants are very diversified and few concepts require further clarification once the first focus group is held and summarized.

❖ The first round of the focus group discussion session includes:

1. production line supervisor,
2. quality control head
3. production planning division staff
4. product design staff
5. production manager
6. sales and marketing manager and

7. plant manager.

❖ The second-round focus group discussion includes:

1. production supervisor
2. production manager
3. two senior machine operators
4. packaging line supervisor and
5. production planning department staff.

In these two rounds, the following issues were clarified and validated: data collected through informal interview, direct observation and recorded of process and set up time, extracted data from production and packaging department raw recorded files such as incoming job order, throughput, production time duration, setup and/or changer over time, processing time, job order arrival probability, number of tardy jobs and WIP accumulation percentage. As a result of these two focus group discussions the data collected can be analyzed using simulation input analyzer and clearly model the production system while precisely selecting the rules that apply directly to the problem stated and nature of the production floor. Similarly, the existing and proposed dispatching rules are assigned to improve the target production parameters, accordingly.

3.1.2 Secondary Data

These data sources are prepared and compiled by the company among the production, sales & marketing and packaging department; articles published on accredited database systems and academics focused book as well as tutorial websites.

- Company's report; production report- this is majorly used to know and understand the variety of products, number of operation per product, number of parts and product category based on design or operation similarity under a given family and/or category; and also to assess the existing scheduling on selected performance parameters. Similarly, the total number of orders placed for the selected products, total throughput, adjusting adequate time range for the study in a way it depicts the usual nature of the production floor status.
- Articles- relevant articles with the selected key words gives emphasis on the tool, data source and even data type to collect and align with the objective stated while considering the case study area's defined characteristics.

- Books and tutorial video- to develop a deep understanding of the data analysis tools selected and proposed to solve the flexible job shop production scheduling problem.

3.2 Methodology frame-work

The high-level of methodology frame-work presented is to precisely propose the approach that can entertain this hybrid MTO-MTS production strategy based flexible job shop scheduling problem. This is to clearly define scientifically proven priority dispatching rules that are developed based on previous secondary data and focus group discussion. It helps to extract unwritten or not clearly recorded working practice to execute the scheduling of the production at different times with targeted performance parameters of the production floor. It mainly considering the production strategy adopted to be competitive in the furniture industry sector.

Dispatching rule with filtered criteria to consider and respective scenarios. Similarly, the simulation tool is used to model and validate the efficiency and stability of the DRs in the production floor operational status focus. The performance measures are the objectives to be met and then the value for them under the existing and proposed based dispatching rules. The performance evaluated and analyzed using the simulation tool; finally, the best performance of the dispatching rules across the most common trend of the production floor defined.

In order to clearly set the scope boundary of the study, the product family category is defined for only kitchen and office. The products are selected using frequent customer order and fast moving items from stock for each product family category. This can clearly define the existing system production operation and respective scheduling practice. Hence, it verify the problem existence on the performance parameters set as objective. Table 3 and Table 4 below represent the products selected, operational sequence, setup time as well as change-over time and processing duration for a unity quantity.

Table 5 Selected products and processing machines

Product Name	**Product Code**	**Machines for processing**
Upper Kitchen Cabinet-Single Door	UKC-SD	All, except Automatic Drilling
Lower Kitchen Cabinet-Single Door	LKC-SD	All, except Automatic Drilling
Upper Kitchen Cabinet-Double Door	UKC-DD	All

Lower Kitchen Cabinet-Double Door	LKC-DD	All
Lower Kitchen Cabinet-Three Drawer	3D-LKC	All, except Automatic Drilling
Coffee Table	CT	CNC, Edge Binding and Semi-manual Drilling
Computer Table	COT	All
Computer with Printer Table	CPT	All
Standard Table-Single Drawer	ST-D1	All
Standard Table	ST	All, except Circular-saw and Handle Boring

Table 6 Products operational sequence and routing

Products	**Original Operational Sequence**	**Alternative Operational Sequence-1**
UKC-SD	CNC>Circular-saw>Edge Binding>Drilling B>Hinge Boring>Handle Boring	Drilling A and Boring machines operation route sequence can change
LKC-SD	CNC>Circular-saw>Edge Binding>Drilling B>Hinge Boring>Handle Boring	
UKC-DD	CNC>Circular-saw>Edge Binding>Drilling A>Hinge Boring>Handle Boring	
LKC-DD	CNC>Circular-saw>Edge Binding>Drilling B>Hinge Boring>Handle Boring	
3D-LKC	CNC>Circular-saw>Edge Binding>Drilling A>Hinge Boring>Handle Boring	
CT	CNC>Edge Binding>Drilling B	Drilling A can be used
COT	CNC>Circular-saw>Edge Binding>Drilling B>Hinge Boring>Handle Boring	
CPT	CNC>Circular-saw>Edge Binding>Drilling B>Hinge Boring>Handle Boring	
ST-D1	CNC>Circular-saw>Edge Binding>Drilling B>Hinge Boring>Handle Boring	
ST	CNC>Edge Binding>Drilling B>Hinge Boring	Drilling A can be used and

Based on the above table, randomly selected months order acceptance and release rate has been collected for the selected products. The months range between the time interval set and the data for the acceptance and release rate of the job orders to packaging section. This implies the inconsistency of the job order dispatching system as the variance cause by the production scheduling. As per the two focus group discussion results it verifies the fact that there exists information flow gaps among horizontal and vertical arranged departments. This resulted in the production performance variability in magnitude as well as incapability of the system to be improved. The major reason is that the root cause hasn't been identified as production monitoring and controlling gap i.e., production scheduling in this case study.

Overview of the production operation once the job order is released from the marketing- where the job order pool is created from both customer and stock- to the planning department is as follows:

Step 1. Job order arrival from marketing department

Step 2. Check the order source as customer or stock

Step 3. If the customer orders, check for the due date; otherwise set the due date based on the existing production plan.

Step 4. Check the customer based job order pool and use one of the dispatching rule

Step 5. Check the stock based job order pool and use compatible dispatching rules that correspond to the customer based job order dispatching rule.

Step 6. Release the job orders to the production floor based on the dispatching rule activated from the planning department aspect.

Step 7. Job order arrival for production from planning department

Step 8. Check for customer based job order and directly align with the planning dispatching rule to start production; otherwise reverse dispatching rule decisions and generate new ones as per the production floor status and potential alignment for better performance measures value.

Step 9. Assign the job order to the machines based on their operational requirement and sequence

Step 10. Sequence job order on a machine based on expertise reference and knowledge to use DR to prioritize the job waiting to be processed on each machine

In the case of unforeseen event, the above mentioned flow of the production dispatching changes as per the type of the event taking place; the potential events which makes the production floor operation dynamic are *new job order arrival, rush job order arrival, expedite job order notification* *and/or extension of due date and design change after sample assembly*. Thus the process flow of the production floor immediately changes as follows setting step 7 as it is for the case of *rush job order arrival and /or expedite job order notification* ; however the other unforeseen events entertained in different patterns.

Step 8'. Check the production operation and start machine setup &/or change over required to process the job order

Step 9'. Immediately revise the previous prioritizing dispatching rule, yet for one time condition

Step 10'. Assign and sequence the operation on each required machine while processing the operation at that time and prepare setup &/or change over on each machine as the new job order route around and visit the machines to be processed on.

In dealing with such patterns of dynamic operation yet vague process flow to capture, the dispatching rule decision making in both departments- planning and production- are the major issues exposed to cause conflicting objectives. This scenario is observed while the production floor is entertaining the multiple as well as mixed product job orders in the hybrid based production strategy. Therefore, the dispatching rule can be categorized at both departments to generate an offline schedule whereby unforeseen events don't take place in; but, still can be used during the online scheduling to manage the dynamic production floor. Chang et al., (1996)study assessed the effectiveness of 42 dispatching rules to use by using data envelopment analysis and the dispatching rules are categorized according to the objective set to be met in a given study scope; similarly, the scientifically proven dispatching rule with slight modification are proposed to be used under the category of performance parameter and production floor status proposed for improvement.

3.3 Consideration Proposed

- Ethical and human consideration: the need to respect any requirement comes from the staff of the company, especially protecting the company secret, design of the process or strategies crafted for competitiveness, and the safety of the employees.

- Operational considerations: the assumption to be considered in the data analysis as well as selection of tools comes from the real-working environment and minimizes the inapplicability of the proposed solution.
- Maintain applicability: structure and propose approach that is applicable to that particular operational feature and requirements while indicating further study areas for improvement from different perspectives.

3.4 Data analysis tools and techniques

As per the data collected and the objective stated in conducting this research, the analysis tools and techniques used to propose compatible production scheduling. This is structured using simulation modeling input and output analyzer, modeling blocks and dispatching rules. Basically commercial version of Arena software used for simulation and priority dispatching rules customized with the production metrics.

3.4.1 Simulation model

This tool is used to synthesize the data collected in a representing format of the system and respective operating conditions. As per the focus group discussion, the production process is sectioned into two and these are:

- Job accepting process- majorly focused on the activity of the marketing and sales
- Dispatching to production process- it basically represents the production floor operating system where assignment of machines and sequencing of the job orders on assigned machines. The process time, sequence, set up time and so on incorporated to realize the real production floor.

3.4.2 Validation and Verification

These two terms are mechanisms to get credibility of the modeled system using the data. In addition to this, the model of the simulation can be cross checked in terms of both qualitative and quantitatively.

- ❖ Validation- this concerns the close diagram representation of the production process and floor by using the modeling blocks and assumptions considered. The simulation model is validated by the production expertise; majorly production manager and supervisor.

- ❖ Verification- based on the validated model, the coded inputs and respective result subjected to verification if the modeled system captured the operational nature of the system. Basically, the verification depends on the availability of data with adequate detail. Therefore there are different mechanism to verify the model. These are categorized as objective and subjective. Due to the lack of well recorded data and reconciliation technique on the available ones, the verification relays on the historical data and confirmation on the operational/production staffs.

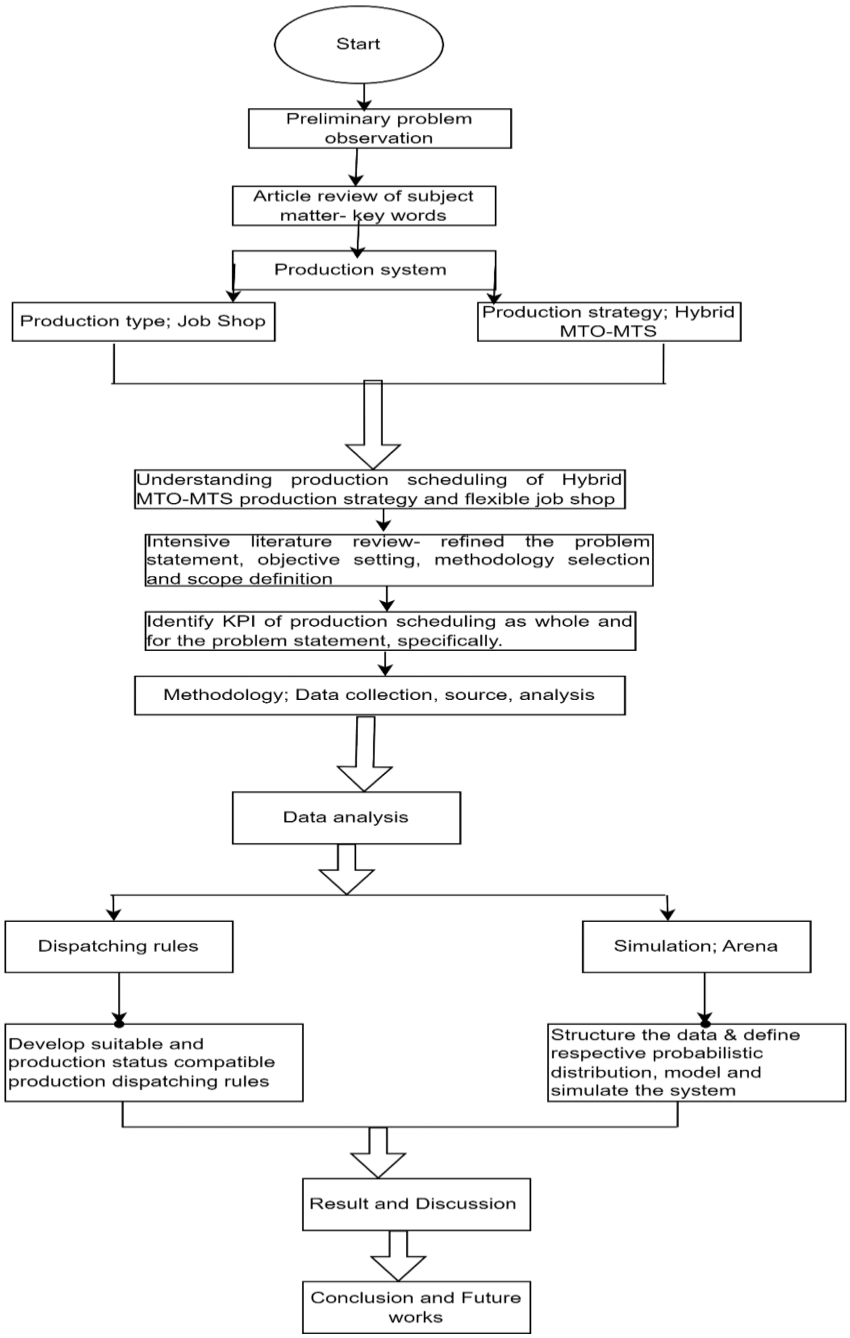


Figure 2 Overall research methodology approach; High-level structural representation.

Chapter 4
Data Collection and Analysis

4.1 Overall production scheduling and operation

Based on the informal interview and production report, the production operation doesn't execute the production based on scheduling that has predictive nature. Instead the reactive rescheduling strategy applies whenever the urgency of job order is determined or informed. The major source of the job order is both from order and stock with minimum job arrival category when transferred to the production floor as well as production planning. This implies the practice of integrated approach for the scheduling instead of the hierarchical approach where the scheduling decomposes into assignment and sequencing.

In order to entertain both the make-to-order and stock, the stock order initiates the customer order for better utilization of raw material unless the customer based order is urgent or due date tightness detected. Thus, the event-driven rescheduling strategy dominates the system production scheduling despite the consideration of the setup time through product similarity and work content of the job order. This might be due to the reason to reduce the set up time, change over between the scheduling rules and resource conflict on each operation of a variety of product job orders. Also the machines could have been assessed for identification of bottlenecks. However, the generation of scheduling still impacts the production delay and reduction of the throughput while increasing the WIP accumulation percentage on the production floor. Similarly, due to the inconsistency of the rescheduling strategy and the respective priority dispatching rule, the production scheduling becomes responsible for any perturbation on the production floor. Especially, whenever there takes place design changes, expedited job order, rush order arrival, setup time and so on.

The scheduling is closely integrated with the planning phase. Due to lack of information flow during operation, the decision making or dispatching of the arrival job order can be executed by the production line supervisor or oftentimes by the marketing department. This leads to disruption of the offline scheduling generated and delay of a given job order. This aggravates the WIP accumulation % and maximizes the tardiness of the production floor as more job orders arrive to the system with unknown requirements. These requirements are processing time, assignment and sequencing of the operation, reactive rescheduling pattern or defined operational procedure.

Based on *Table 1*, the total office and kitchen production counts, the selected product types comes as work order on date ranging from **Sep 2020- Feb 2022 G.C** gives a total of 2408 work order . These work orders received for the selected product families and product types where there is an average of the selected products- *7 individual product per an order sheet*. Since the production floor is a job shop, the available machines can operate or process different products using setup adjustment whenever a new job order is released to the production floor. In addition to this, there exists a flexibility on the two operations out of the five operations carried out to produce all the product variety. The furniture production floor contains five machines each with different setup time and configuration.

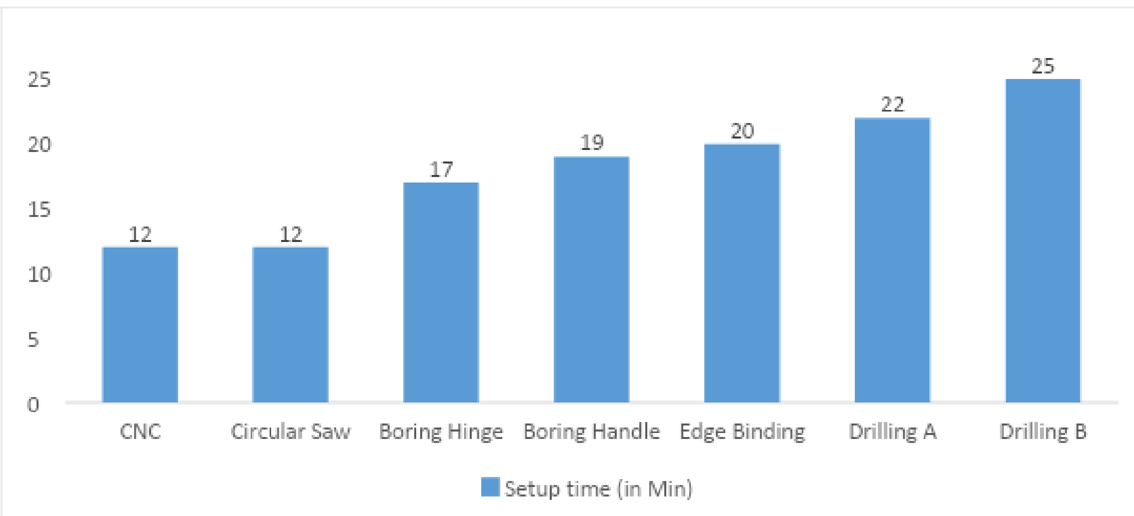


Figure 3 Setup time required for the machines

Since, the production strategy is hybrid MTO-MTS and the production type being a job shop with partial flexibility the production floor is subjected to address the job orders as follows based on the order type and products mixture. Using informal interviews with the production and planning department staff, the following production mode developed for better understanding of the complex production scheduling practice and respective dispatching rules used. Majority of the scheduling approach was devised based on the experience of the decision maker in the production floor-production head, supervisor and foreman.

Table 7 Production modes based on product family type and order type.

Type of Modes	Type of product	Type of order
Mode 1	Single	Single
Mode 2	Mixed	Mixed
Mode 3	Single	Mixed
Mode 4	Mixed	Single

Based on the above table production modes, mode 2 and 4 are the most frequent production scenarios where the production scheduling falls into disruption most of the time and clearly strives to manage the resource constraints with the job order arrival characterized by randomness. Similarly, the production scheduling rules or dispatching rules are based on the following criteria: board waste minimization, customer order/rush order priority, total machine requirement. In the hybrid MTO-MTS production strategy, the production nature exhibits both the static and dynamic features of production. As mentioned on (Chang et al., 1996; Thenarasu et al., 1800)studies the need to apply dispatching rules given the current status of the production to propose hybrid of static and dynamic dispatching rules and evaluation of the dispatching rules for the criteria and/or performance measures; thus the existing dispatching rules and respective criteria and performance parameters are presented below.

Table 8 Existing dispatching/scheduling rules of the production floor

Dispatching rules	Static production operation	Dynamic production operation
Customer priority	Not applicable	Applicable
Board minimization	Applicable	Not applicable
Machine requirement	Applicable	Not applicable

The scheduling rules are usually evaluated using the performance measurement of the production floor and these are production volume or throughput, material (board) utilization, delivery date and stock replenishment. This multi-objective requirement of the production performance parameter indicates the need to scientifically designed dispatching rule for both static and dynamic operation feature of the production. Therefore, (Chang et al., 1996) concept can be used to classify the rules based on the target performance parameter as well as operational status of the shop floor at that particular moment.

In the most frequent cases a particular concern given to the customer order and delivery date as criteria and performance parameter, respectively. The need to consider setup time during or at the start of operation and changeover impacts the final result and operational smoothness especially taking into account the production modes developed from work order data.

Table 9 Setup time and changeover time of the machines

Machines	**Functionality**	**Set-up time**	**Change over time**
CNC	Cutting machine	15	8
Circular-saw	Grooving machine	15	8
Edge Binding	Laminating the visible section of the parts	20	11
Drilling Automatic	Drilling for fastening	22	21
Drilling Semi-manual	Drilling for fastening	25	24
Hinge Boring	Boring for hinge and cable pass	17	15
Handle Boring	Boring to fasten the handle	14	9

In reference to the above given data for setup time- at the start of the production operation- and the two change-over time for the selected product type and family, the total setup time is determined to be *127min (2hr & 7min)* and the change over time between similar product family. Different product family set up time set to be *85min (1hr & 25min)* and *107min (1hr & 47min)* respectively. The time measurement for the processing time of the selected products is based on the number of parts being processed or operation time for each machines except the CNC. CNC machine time measurement is derived from the square meter of the board material processed per a single setup. This means each product square meter is determined from the cutting list and its processing time on CNC machine is computed using the time taken to cut the standard size of the board and respective unit product square meter as total for each part.

The selected product types are *10 in total*; *5 under Kitchen family and 5 under Office family*. The very basic reason to select these products is due to the demand volume despite the seasonal market change as with other products. Majority of the customers are mostly engaged in frequent purchases of these products. For instance, banking organizations, hotel and restaurant as well as home user. The products require design change over size change to be considered as a job order waiting to be scheduled; thus the size difference can be compromised on the three product types selected. For the case of the upper kitchen cabinet there are two types of design and similar for the lower kitchen cabinet and also for the one with three drawers. The need to define setup time and two categories of change-over time as similar and different products is to have deep insight of the time constraint in delivering the job order when the customer priority dispatching rule is activated. The effect impacts the other job orders generated by the customer as well as stock based order. But from the concern to minimize the complication of the scheduling requirement while modeling the existing system average of *96min* is taken for change-over time while maintaining the set-up time as *127min.*

4.1.1 Dispatching rules; existing and proposed

a. Existing dispatching rules

As mentioned above, the existing dispatching rules the manufacturing floor shop using are as follows:

- Customer priority- majorly focuses on the orders coming from the two sources of customer orders-individual through walk-by showroom and client through tender/work bid. The production - the on-run-can be set to pause to proceed with the most urgent job order and the rest follow based on the order source and due date/urgency.
- Board waste minimization- the job orders scheduled according to the product family type as the board-raw material for production- is different among the two product family types; thus the rule is capable of entertaining the production despite the order source of the job

order found in the job pool. As a result, the waste is minimized as targeted even though production delay is at high risk and increment of job order pool size while the stock reorder level keeps dropping down.

- Total machine requirement- the job orders scheduled based on the machine required to process and this doesn't always hold the same value as the production floor status is dynamic-in any condition the rule either selects the least machine number or the most machine number requiring job order - as well as the job order pool product type mix. This is exercised to manage the throughput value for that specific period-weekly or monthly - performance.

b. Proposed dispatching rules

Based on the the production scheduling efficiency and effectiveness, one of the gaps observed is the incompatibility of the dispatching rules being used. The following are the newly proposed dispatching rules in relation to the objectives set to be optimized.

- Number in queue (NINQ)- the job order is scheduled based on the number of queue on the next operating machine. The fewest number in the queue is selected first and followed by the job order whose next operating machine has the second fewest number in the queue.
    - ➢ Potentially targeted objective through this DR is/are- throughput, makespan and number of tardy jobs
- Least/Shortest subsequent operation (L/SSO)- the job order is scheduled with the shortest time of the subsequent operation.
    - ➢ Potentially targeted objective through this DR is/are- makespan and number of tardy jobs
- Least/Most total work (L/MTWK)- based on the job order pool size and mix of product type then a job order is selected for either the least or most work content(number of parts to operate on before sending to packaging).
    - ➢ Potentially targeted objective through this DR is/are-WIP accumulation percentage, makespan and throughput
- Shortest set-up time (SST)- this is basically based on the previous job order type and respective time required to shift to one of the available job orders from the job order pool

and/or rushed job orders. Job selected with the shortest set up time to resume/continue the production process.

- ➢ Potentially targeted objective through this DR is/are- makespan WIP accumulation percentage

4.1.2 Development of Simulation Model

a. <u>Overall model description</u>

The application of a simulation model can give a clear understanding of the real experiment desired to carry out and capture the potential feasible scenarios while maintaining economic viability to perform it in the real active system. Therefore, simulation is a tool used to compare the "As-Is" system with that of the "To-Be" system.

The developed model represents the production system and respective scheduling in two model sections. The two models are linked with the model logical connection mechanism. The first section of the model depicts the paper-workflow. Paper-workflow is whenever an order or set of orders is placed and transferred to the production floor to be managed as per the scheduling approach activated to govern it. The second section is dedicated to represent the production floor management (this where majority of the scheduling method/technique used, especially the dispatching rules). In the development of the model with both conceptual and computational model content the following parameters are defined precisely. These are:

- Input- Due-date, processing time of each product and machine, processing sequence, product part, percentage of each order source and also product family, existing condition for dispatching.
- Output- Throughput/number out, WIP accumulation percentage across each workstation (except CNC), number of tardy job orders from both customer order and stock order and completion time, number of incoming order and dispatched order, number of customer and stock order and number of immediate and scheduled production order.
- Assumptions
  a. Each operation can only be processed on one machine
  b. Each job consists of a set of operations with predefined assignable machines and processing time.
  c. Jobs are independent of each other

d. Preemption and interruption aren't allowed
e. Each machine can process at most one operation at any time
f. Set-up time is constant and set as warm-up period in the model.
g. change-over time of the machines are constant across the same product family type and also from one family type to the other.
h. Transport time, machine break-down, manpower skill and material starvation aren't considered.
i. All machines are available at the beginning of the production
j. Selected products are the products considered active for both stock and customer.

- Performance indicators- Completion time, throughput, WIP accumulation percentage and number of tardy jobs.

b. Simulation run setup

In system simulation the consideration set in the run setup has the power to decide whether the model can be used to suggest potential solution alternatives or not. Most of the factors affecting acceptability of the simulation result comes from the run time length and number of replication. The run time length directly connects with the validation while the number of replication makes the verification of the simulation model and respective output with that of the real system.

Basically, it reduces the probability of error and gives reasonable output value-close to reality- to make a decision for. The simulation length is set to 457 days and replication of 20 with 8 hrs. of working time. The data taken for the study is *1year & 6months* and this gives 457 days excluding holidays and Sunday as weekend. Based on the reviewed literature on application of a simulation tool for production scheduling project studies, the reliable replication number for a variety of products and stochastic processes is >= 15. The replication number tested by using the half width for similar models.

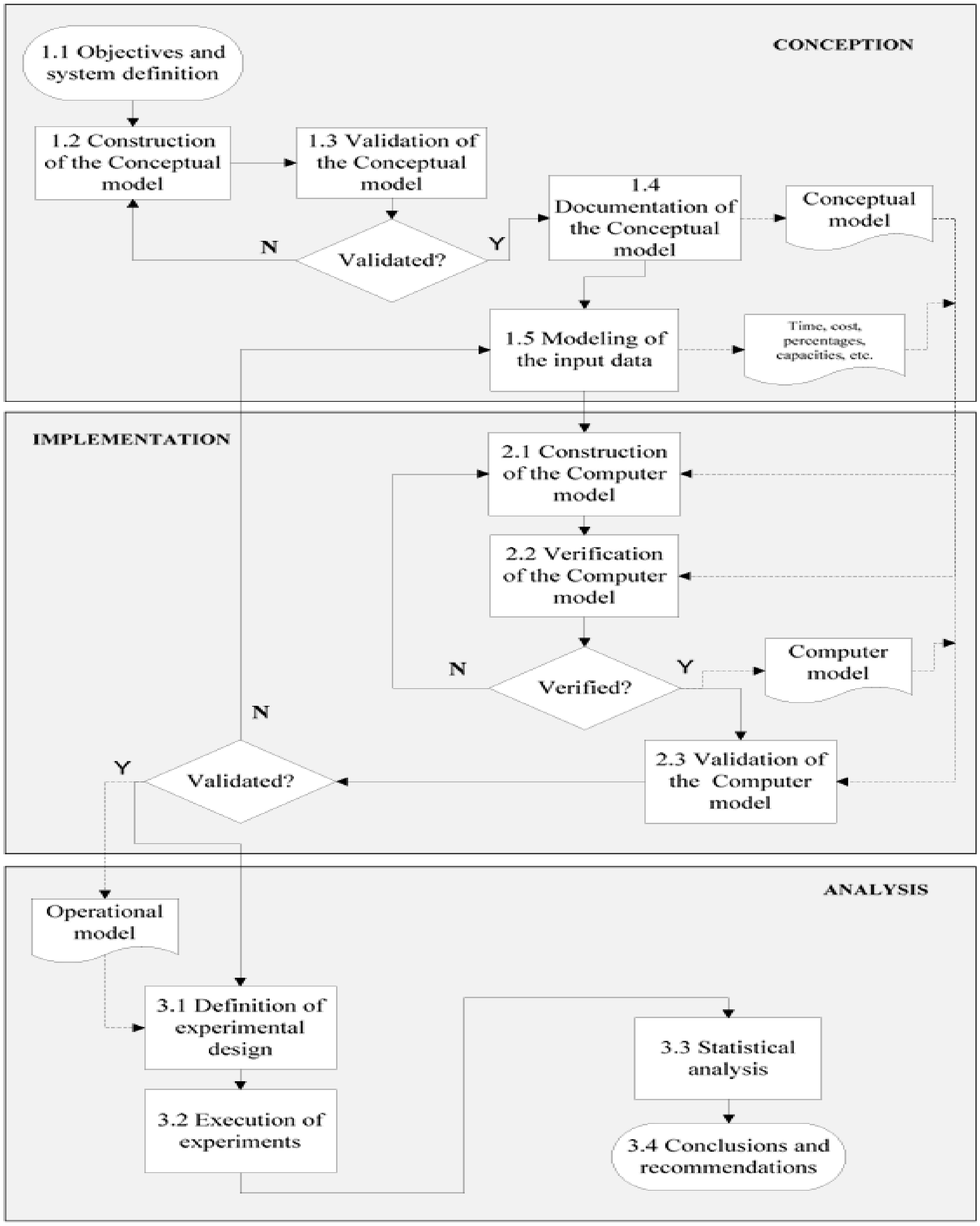


Figure 4 Simulation model development; conceptual and computational model

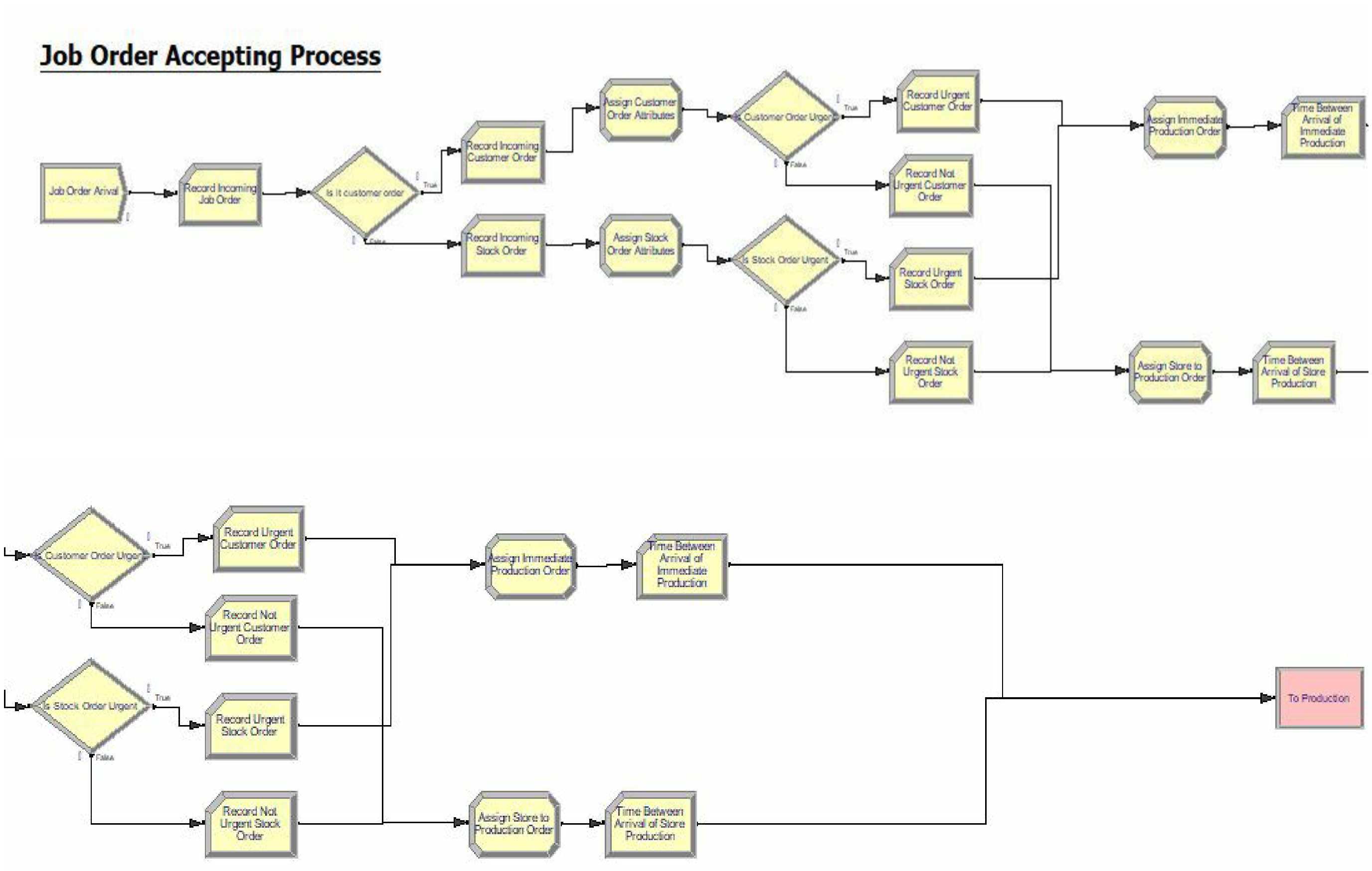


Figure 5 Simulation model representation of the production scheduling in two section; paper-work flow.

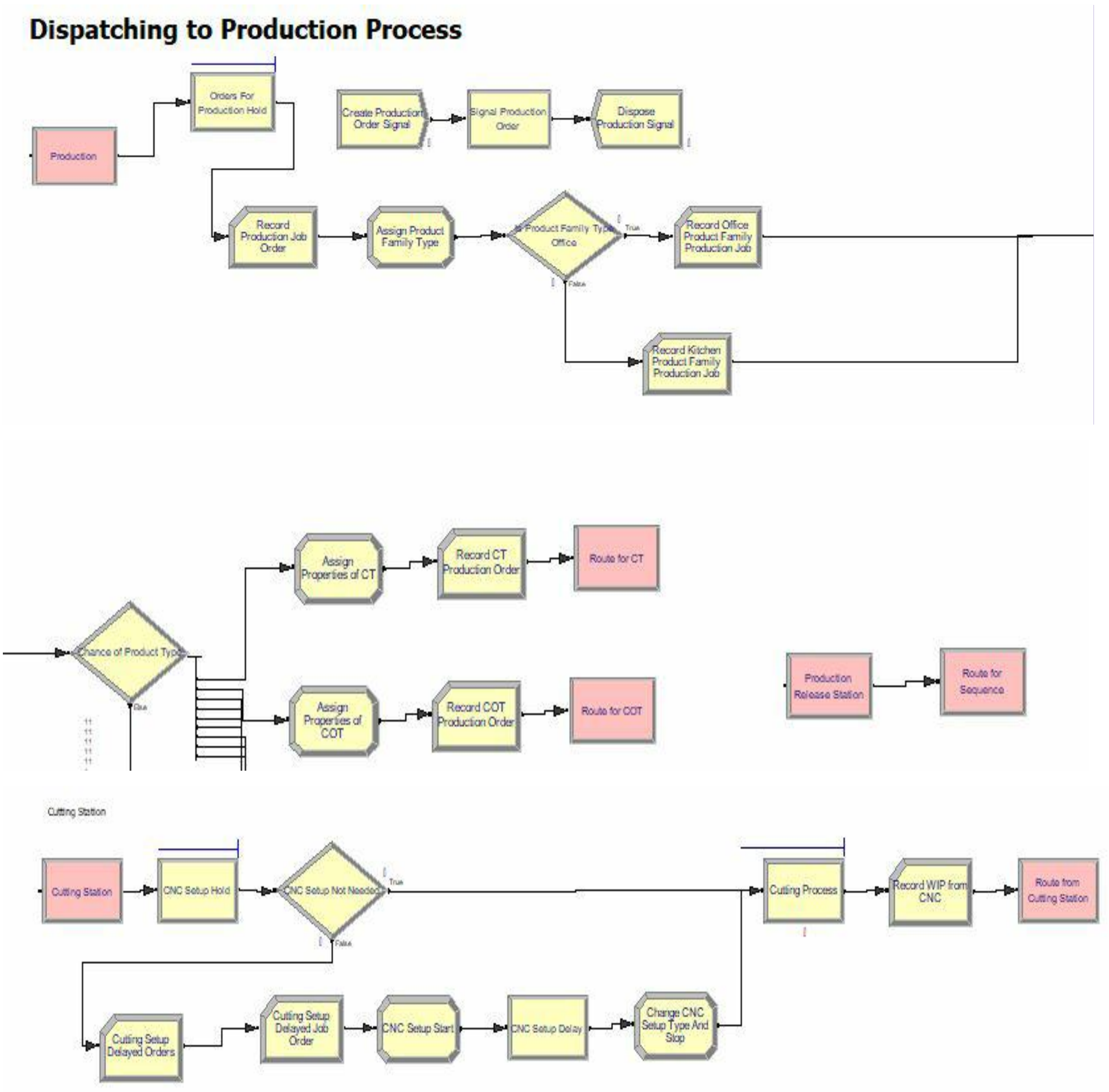


Figure 6 Simulation model representation of the production scheduling in two section; dispatching to production-production floor

Validation and verification are activities carried out before the experimental phase. These two terms used to ensure that the developed model actually represents the real system, within the assumptions developed for the model. The schematic representation of the sequence of steps for proposed simulation in Figure 7 shows the placement of these activities while developing the conceptual as well as computational model. Basically, the validation concerns the correct representation of the system by the model in skeletal/structure of data while the verification assures that the coded inputs into the model can generate output value with tolerable degree of error since there is no way to 100% validate model as virtue fact. The model is expected to be valid in the sense of satisfactorily representing reality while only including elements that affect the problem to be solved in the simulation project. Always the conceptual model validation leads to the valid computational model development and the verification aligns accordingly.

c. Pilot run of model; result and summary

Based on the data collected and analyzed, the simulation has realized and pilot run for the existing production scheduling approach is carried out. As per the objective of the study, the performance metrics are the focus areas from the generated simulation model report. The overview of the base existing model without specifying those dispatching rules-rules acquired through experience and knowledge of the production floor- implies that lack of inconsistency practice hinders the production floor to use its capacity and be on continuous improvement. This very concept captured through the time between when production floor accepts immediate and scheduled/store to production job orders. For the base model of the system the time between is recorded as 19 days.

i. Completion time

This is the total time used to produce an output of 2411 job orders (products of the selected type). As for the case study, the time is taken as 457 days as maximum value but the average maximum time of 243 days gives clue that 47% of the maximum time duration is used to process job orders that are tardy job order.

ii. Throughput

Throughput of the production is the number produced as ratio of time used for production. Similarly, the inconsistency of the dispatching rules affected the number of output per a day-8hrs/day. The base existing system dispose 35 products per a day.

iii. WIP accumulation %

Depending up on the applied dispatching rules, the WIP accumulation percentage to that of the dispatched to number of job orders gives clear insight of how effective the scheduling is working. Hence, the existing system has 82% of the dispatched job order as WIP inventory and average of 1992 job orders from treated as WIP during the 457 days of production.

iv. Number of tardy job

The company doesn't have the proper record of the number of tardy job order and through the derivation made from the incoming job order log and with that of the packaging section transfer log. The overall data shows that close to half of the incoming job orders processed after certain time of duration. This is verified through focus group discussion used and the work study reference-shows that the company runs slightly higher than half capacity- conducted by the company. Therefore, the base model of the existing system shows 1277 tardy jobs processed.

d. Proposed dispatching rule; improvement

From the existing production scheduling approach and overall production system performance, the improvement section has segmented and focused towards developing consistent and scientific sense based dispatching rules. Initially, the production scheduling based challenges addressed and taken as performance metrics to improve as objective of the study. Based on the data collected and interpreted as the first phase of the research, the selected metrics can be improved by the proposed DRs. These rules are customized and clearly coded to the model for the result captured while maintain the features of the production floor such as: production floor type, product type and variety and production strategy.

As an overview, L/MTWk dispatching rule gives the highest output and the base proposed system-partial flexibility of the job shop on the drilling operation- gives the least average WIP accumulation % and SSO enhanced the production floor immediate as well as scheduled/store to production job order volume (1644 and 781), respectively. The number of tardy job orders reduced and almost the floor capacitated to use 55% of it to deliver 230 more job orders. In addition to this, the time between the immediate and store to production reduced to 14days compared to the 19 days on the existing base model of the system.

Chapter 5

Result and Discussion

Based on the result, the general base model of the existing and proposed system indicate that the production scheduling does affect the overall performance of the production floor. The selected performance indicators are complementary one to the other; therefore the improvement in one of the parameters positively affect the rest of the metrics.

The result on this two general system models (base model of existing and proposed) shows similarity on how the governing dispatching rule makes difference on one or two of the performance indicators.

From the existing dispatching rules, the board waste minimization (BWM) rule gives the highest output 2435 job order products and the total machine requirement (TMR) rule gives the lowest level of WIP accumulation percentage of 71% as well as number of tardy job 1270 job orders.

5.1 Existing Dispatching Rules

5.1.1 Customer priority (CP)

In this dispatching rule, the existing scheduling is run based on the usual trend of job shop production which typically gives priority to the customer order. This indicates that the hybrid strategy needs flexibility to accommodate such orders and this can be achieved through a compatible production scheduling.

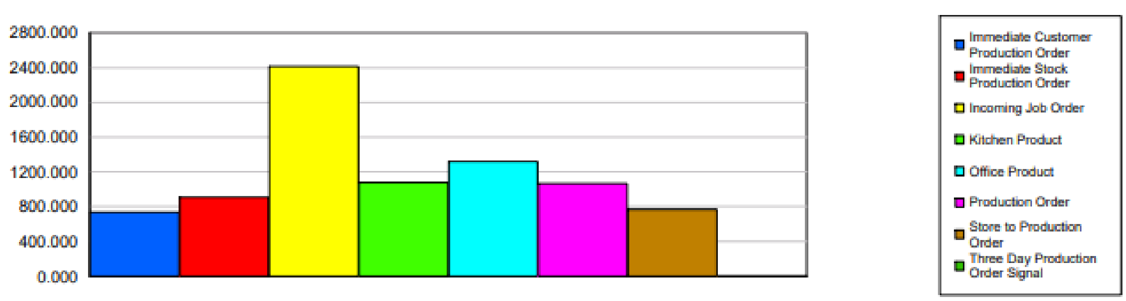
As for the general performance metrics of the production scheduling under study, the throughput and WIP accumulation % are the key drivers for the other factors of production throughput improvement in the partial flexible job shop with hybrid production strategy. The customer priority(“CP”) dispatching rules yields the second higher WIP accumulatio % of 83 and number of tardy jobs of 1308 for the time period interval the study conducted in.

Other indicators can be taken from the report are the time between the production floor entertained the immediate production initiated for the customer based order and also the stock order labeled as immediate. Immediate production comes to the production floor approximately 2hr and 30min while the store to production/scheduled production every 5hrs of the working time. The number of the tardy job increased as result of this short span of time in between of the production initiated.

Table 10 Results of CP DR of the existing scheduling approach

Performance metrics	Result of CP dispatching rule
WIP accumulation %	83%
Completion time (average)	227 days
Throughput	73 product/day
Number of tardy jobs	1308

Number In	Average	Half Width	Minimum Average	Maximum Average
Immediate Customer Production Order	735.53	30.08	670.00	837.00
Immediate Stock Production Order	908.47	24.75	827.00	995.00
Incoming Job Order	2412.60	71.80	2205.00	2619.00
Kitchen Product	1077.27	34.59	981.00	1186.00
Office Product	1320.93	47.94	1170.00	1494.00
Production Order	1065.87	46.76	945.00	1274.00
Store to Production Order	768.60	26.91	679.00	856.00
Three Day Production Order Signal	0.00	0.00	0.00	0.00



Between	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Tally Immediate Production Order	0.2778	0.01	0.2555	0.2990	0.00	13.6745
Tally Store to Production	0.5948	0.02	0.5307	0.6717	0.00	14.0442

Figure 7 Time Between and Number in of CP DR

5.1.2 Board waste minimization (BWM)

Board waste minimization(“BWM”) dispatching rules focuses on minimizing the scrap and related cost of the production while entertaining the a given production scheduling to run the production. However, the adopted production strategy- hybrid- is not compatible and resulted in the highest WIP accumulation % of 86 but improved tardy jobs and throughput of the production in a day. This indicates that, the DR is applicable when the make-to-stock job order volume is higher than the make-to-order and with less urge to release them from the line.

This rule enable the production floor to collect similar product family and dispatch to production without majorly considering the immediate customer and/or stock job order for production. The time between for immediate production order has wide span of time while the store to production has narrow time span.

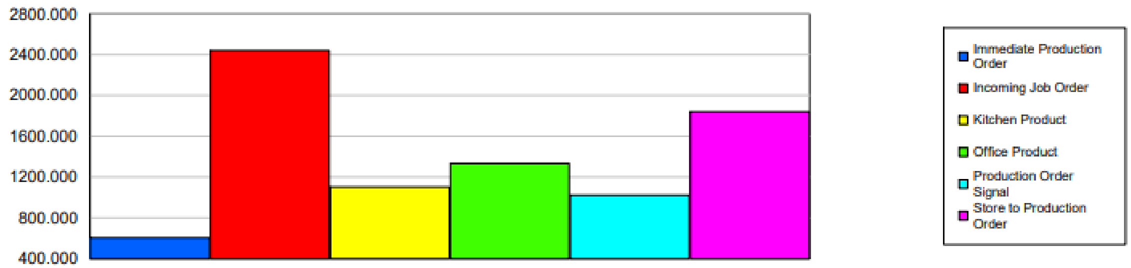
Table 11 Results of BWM DR

Performance metrics	Result of BWM dispatching rule
WIP accumulation %	86%
Completion time (average)	227 days
Throughput	75 product/day
Number of tardy jobs	1304

Between	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Tally Immediate Production Order	0.7588	0.03	0.6569	0.8448	0.00	16.9773
Tally Store to Production	0.2479	0.01	0.2179	0.2697	0.00	15.3348

Figure 8 Time Between of BWM DR

Number In	Average	Half Width	Minimum Average	Maximum Average
Immediate Production Order	602.60	25.27	538.00	690.00
Incoming Job Order	2443.20	77.65	2241.00	2763.00
Kitchen Product	1102.73	34.43	1015.00	1223.00
Office Product	1332.67	46.41	1222.00	1531.00
Production Order Signal	1021.07	43.78	896.00	1218.00
Store to Production Order	1840.60	56.93	1684.00	2092.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
Immediate Production Order	601.00	24.94	538.00	690.00
Incoming Job Order	2443.20	77.65	2241.00	2763.00
Kitchen Product	1102.80	34.64	1017.00	1223.00
Office Product	1331.73	46.18	1222.00	1532.00
Production Order Signal	1021.07	43.78	896.00	1218.00
Store to Production Order	1834.40	57.70	1684.00	2085.00

Figure 9 BWM DR of the existing production scheduling approach

5.1.3 Total Machine Requirement (TMR)

The major focus for this DR is on the dispatching of job order to the production floor and clearly defining the operation sequence. As a result of this combined and hirearchical integration these tow production scheduling decisions, the DR recorded the lowest WIP accumulation% of 71 and number of tardy jobs of 1270. Similar to the previous rules, the time between the immediate and store to production relatively better to the base existing system model which is 19-day time of interval.

Table 12 Result of TMR DR in the existing production scheduling approach

Performance metrics	Result of TMR dispatching rule
WIP accumulation %	71%
Completion time (average)	232 days
Throughput	70 product/day
Number of tardy jobs	1270

Between	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Tally Immediate Production Order	0.7613	0.03	0.6923	0.8969	0.00	15.4969
Tally Store to Production	0.2597	0.01	0.2377	0.2968	0.00	14.4570

Figure 10 Time Between of TMR DR of the existing production scheduling approach

5.2 Proposed Dispatching Rules

The major component of the proposed base model of the production scheduling arises from the concept of the partial flexibility of the production floor for the drilling operation and the need to equally entertain the hybrid production strategy.

5.2.1 Summary of the proposed rules: NINQ

The major component of the proposed base model of the production scheduling arises from the concept of the partial flexibility of the production floor for the drilling operation and the need to equally entertain the hybrid production strategy.

The proposed base model of the system result becomes similar to the next in queue (NINQ) dispatching rule. This is mainly due to the governing rule which considers the queue length. Meanwhile the drilling section has found to be the work station which requires this queue based rule other than the rest of the work station as it exhibit limited flexibility.

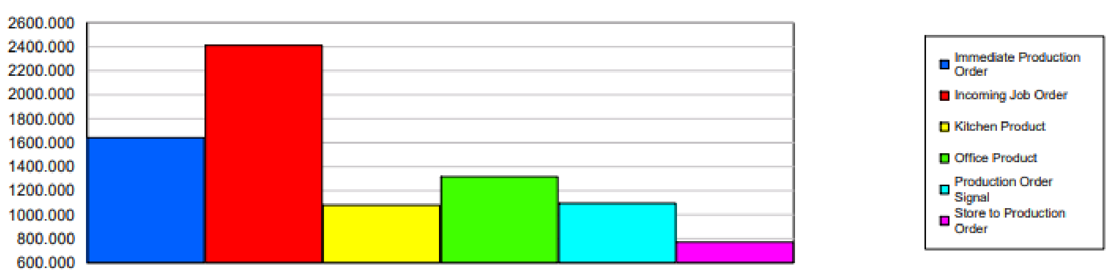
This DR is crucial in eliminating the WIP accumulation on the production floor and minimizes the number of tardy jobs at the same time. The WIP accumulation% of 76 with the lowest number of 1078 for the tardy job orders. As a result the capacity to accept new job order is feasible scenario where the hybrid production strategy exploited further.

The overview of the existing and proposed base models clearly shows the significance of applying and using the partial flexibility of the production floor almost from every corner of the production floor performance metrics even though the output generated reduced from 2411 to 2397 job orders. The result is presented as follows:

Table 13 Proposed base system of scheduling and NINQ DR

Performance metrics	Result of Proposed dispatching rule
WIP accumulation %	76%
Completion time (average)	231 days
Throughput	72 product/day
Number of tardy jobs	1078

Number In	Average	Half Width	Minimum Average	Maximum Average
Immediate Production Order	1642.47	52.72	1520.00	1862.00
Incoming Job Order	2411.40	80.21	2223.00	2673.00
Kitchen Product	1079.13	41.66	982.00	1218.00
Office Product	1316.07	46.85	1196.00	1457.00
Production Order Signal	1095.27	53.32	994.00	1358.00
Store to Production Order	768.93	33.05	669.00	864.00



Between	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Tally Immediate Production Order	0.2780	0.01	0.2445	0.3006	0.00	14.5302
Tally Store to Production	0.5955	0.03	0.5266	0.6821	0.00	14.5302

Figure 11 Time Between and Number in of proposed base model and NINQ DR

5.2.2 Summary of the proposed rules: L/MTWk, SST and SSO

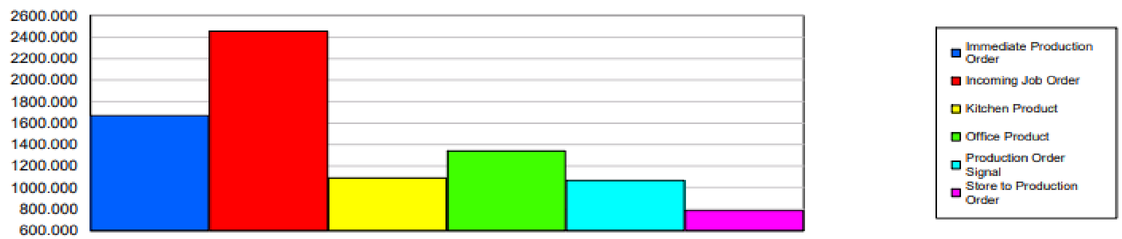
In the application of the proposed DRs, the WIP accumulation as well as number of tardy jobs showed a significant improvement while the throughput remained almost the same and increased compared to the existing DRs except the BWM which is 75 job order/day with the lowest average completion time of 227 days.

The completion time considered under the study is 457 days and gives out nearly the same throughput. But the average completion time of both the existing and proposed DRs implemented improved the average completion time by more than half i.e. 50%.

Table 14 Result obtained of the proposed DR scheduling approach.

Performance metrics	L/MTWk	SST	SSO
WIP accumulation%	76%	76%	76%
Completion time(average)	233 days	230 days	231 days
Throughput	73prod/day	74 prod/day	74 prod/day
Number of tardy jobs	1078	1213	1214

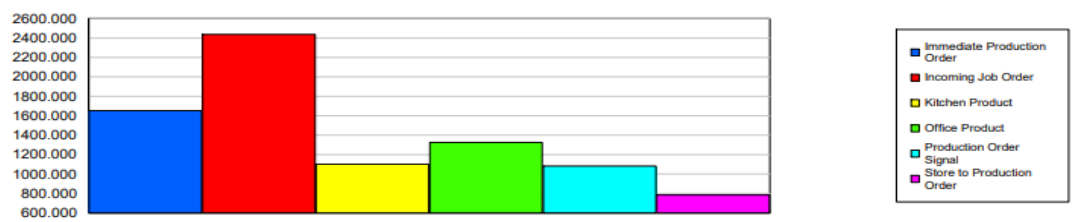
Number In	Average	Half Width	Minimum Average	Maximum Average
Immediate Production Order	1670.27	63.04	1455.00	1893.00
Incoming Job Order	2454.60	88.72	2133.00	2745.00
Kitchen Product	1090.73	43.63	930.00	1230.00
Office Product	1339.27	48.35	1131.00	1452.00
Production Order Signal	1065.87	41.92	903.00	1225.00
Store to Production Order	784.33	30.24	678.00	860.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
Immediate Production Order	1654.67	63.18	1407.00	1850.00
Incoming Job Order	2454.60	88.72	2133.00	2745.00
Kitchen Product	1091.00	43.46	930.00	1231.00
Office Product	1340.13	48.46	1131.00	1455.00
Production Order Signal	1065.87	41.92	903.00	1225.00
Store to Production Order	775.33	31.17	654.00	856.00

Figure 12 Number in and out of L/MTWk DR of the proposed scheduling

Number In	Average	Half Width	Minimum Average	Maximum Average
Immediate Production Order	1651.80	46.15	1463.00	1763.00
Incoming Job Order	2436.60	77.78	2151.00	2628.00
Kitchen Product	1100.47	37.00	972.00	1204.00
Office Product	1324.73	48.00	1132.00	1455.00
Production Order Signal	1082.67	45.93	938.00	1190.00
Store to Production Order	784.80	34.20	656.00	900.00



Number Out	Average	Half Width	Minimum Average	Maximum Average
Immediate Production Order	1644.00	49.02	1457.00	1759.00
Incoming Job Order	2436.60	77.78	2151.00	2628.00
Kitchen Product	1101.87	36.87	972.00	1206.00
Office Product	1326.20	47.96	1134.00	1455.00
Production Order Signal	1082.67	45.93	938.00	1190.00
Store to Production Order	781.20	35.06	646.00	896.00

Figure 13 SSO DR

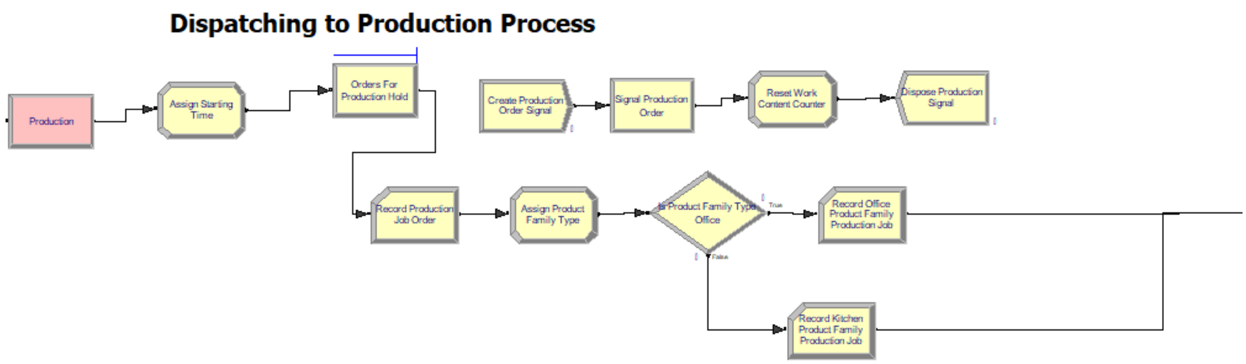


Figure 14 Simulation model adjustment of the L/MTWk proposed DR to govern the dispatched job order

Chapter 6

Conclusion and Recommendation

6.1 Conclusion

In a more dynamic and custom-made based market of the furniture industry, the need to be on continuous improvement is mandatory. The quality of product for such products comes from the delivery time and overall production floor efficiency. In this context, the furniture manufacturing strives to fulfill conflicting interest of the internal and external shareholders of the industry sector.

The production floor efficiency and delivery time improvement majorly attained through the production scheduling. Hence, the research focused on production scheduling of Deluxe Furniture which exhibits job shop with partial flexibility and hybrid MTO-MTS production strategy. The main objective of the study lies on improving the throughput of the shop floor, minimize the WIP accumulation percentage and number of tardy job.

As analyzed using simulation tool, the existing production scheduling lacks consistency and the average WIP accumulation over the study time result to be 80% and this implies the number of tardy jobs are higher than the proposed which is 76%. Similar to this, the capacity to accept and process the job orders under the immediate/urgent production and stored/scheduled production orders improved with 5 days as maximum value and average interval between is *2hr and 30min and 4hr.* The output and number of tardy job orders across the existing and proposed dispatching rules gives clear understanding of the production scheduling significance.

6.2 Recommendation

Based on the status of the production floor these proposed and also combined with the existing dispatching rules can be used to improve one or more selected performance metrics as designed by the managerial team. For instance, the TMR rule of the existing system can be used to reduce the average WIP accumulation percentage while the BWM combined with LMTWk preferred to maximize the output as well as maintain the low level of the average WIP accumulation percentage.

Similarly, with thorough analysis of the products dispatched to production these rules can be selected across the number of certain defined product type or product family category.

During the focus group discussion, the WIP accumulation raised as the burning issue as other quality related issue arises both at the production as well as packaging section. As a result the number of tardy job increased and almost half of the maximum time duration to complete the output record on the packaging log, 2408 job order products, is used to deliver tardy job orders. Hence, the result of the proposed DR can be combined with the basic DR the company were exercising to smoothen the conflicting stress on the production floor. This majorly comes from the misalignment of the production strategy adopted by the production floor and ignorance of the partial flexibility nature.

As overall recommendations, the company can use the product seasonal nature and use the stock strategy with accurate forecast and practice the proposed and existing DR pros and cons with other innate features of the production floor.

6.3 Future research areas

This similar production scheduling issue can be merged with the supply chain and inventory management, the quality control and assurance centering on the rework, scrap and board waste minimization consideration. These concepts can be taken as future work areas to further enhance the overall performance of the manufacturing firm while leveraging the advantage of the shop floor partial flexibility and hybrid MTO-MTS production strategy.

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Annex

A. Informa Interview Questions – Deluxe Furniture Manufacturing

The following informal interview conducted among the production line supervisor/team leader, machine operators, production manager, quality manager, design department staffs and plant manager.

1. How do you carry out the production process in regard to production scheduling for both make-to-order and make-to-stock? Is the scheduling developed using integrated or hierarchical
2. How often do you think production disturbance events take place weekly or monthly? Mention the potential production disturbance events
3. How do you usually generate a production scheduling for the overall production system- considering the hybrid nature of the production strategy being used? Is the production static or dynamic in your terms of understanding and appropriate scenarios as justification
4. How do you entertain unforeseen events- new job order arrival, expedited job orders, excess WIP accumulation on the production floor, due date extension, and design changes- taking place during actively running production scheduling?
    - Is there any method/technique for production scheduling being used in the current production flow?
    - What is/are the key performance indicators of production system and respective scheduling technique used?
5. What is the production share of the identified categories for both make to order and stock?

B. *Focus Group Discussions*

In this section of the data collection method, the production department staffs took majority of the discussion with minority participation from quality and marketing and sales managers. This mixture of staffs involved in the discussion group provides the wider scope to understand the fact that the problem stated exists with factual data and implication on how it is also affecting the performance of the other departments with list of indications for future research work intervention areas.

- **Date-** Friday, June 10, 2022 G.C(Part I and Part II); Tuesday, June 14,2022 G.C (Part III and Part IV)
- **Place** – Deluxe Furniture Manufacturing Plant / Training Room
- **Participants**

Department	Job Description	Name of Participant
Planning	Develop production plan, review the production status according to the plan and record respective issues and prepare reports.	Robel
Production	Manage the production floor and receive production order from planning, assign and sequence the job order parts, check the sample assembly, facilitate the setup and follow up machineries maintenance.	Abdu
Quality	Prepare quality check list and parameters, control quality at each workstation and confirms for shipment from the production to packaging and from packaging to store or customer shipment.	Andualem
Design	Draw product design as per the planning department and confirms with the production for final release to the machine operators.	Bereket
Planning	Assist in planning process and prepare BOM and review raw material availability and finished product in stock, check and estimate due date with the production status of the floor.	Beza

Management	Overall manufacturing plant management from marketing to supply and production in the middle both for material and information flow.	Mesfin

❖ **Objective of the focus group discussion sessions**

Based on the support letter submitted to the company management, the focus group is proposed to be conducted as data input to understand the existing production scheduling and then respective analysis developed to propose feasible and then optimum scheduling solution for a better performance of the production floor with set of parameters such as throughput, WIP accumulation % and maximum tardy job orders.

I. <u>Part One/ Focus Group Discussion Session I – Overall Operational Procedures</u>

A. Brief description of the production process; end-to-end

- Andualem

- Detail drawing of the product>BOM>check the drawing and BOM>material request form> material supplied from raw material warehouse> cutting on CNC machine>edge binding on Binding machine> grooving on Circular Saw machine> drilling parts distribution based on size on Drilling A and B>hinge and handle boring on Boring A and B respectively> Sort by part name> shipped to packaging.
- Every machine has its own quality check list for the part being processed before transferring to the next operation or machine. Similarly one last round quality checking and control carried out before shipping to the packaging/assembly section of the production floor.

- Beza

- Order taken from the marketing department for both customer and stock type of orders and then develop plan for the order completion time and BOM preparation based on the specifications; thereafter the finance takes for cost development and return to the marketing department. The production floor process is similar to my colleague Andualem briefing and the only point I can add is that, we frequently come across information gap to spot out which product is where to monitor accordingly to the planning we set for week and/or month.

- Robel

- In the production process, there is only defined route for a single product design however if a slight design changes the routing of the parts immediately changes and this tells that we have somehow flexible job shop floor which enables us to do both multi as well as mixed production processes. In order to minimize the rework and scrap rate of the production floor, each part of the product processed and sample assembly checked for the other parts to proceed since the setup time for the drilling and cutting machine is longer than other machines and irreversible quality issue arises at this stage of the production.

- Abdu

- As mentioned by Andualem, I also take in charge of the main production floor based on the plan released from planning department and all the necessary raw material and machinery tools availability confirms. Ofcourse, the production floor has the capacity to produce multiple product types while managing the constraints of machines, manpower and working space/buffer zone. Based on the product type the process sequence has flexibility to some degree therefore we often swap to save time and minimize idleness of machines. Each operation has quality sample based on the order size and respective setup time for the machineries to resume production somehow considered to meet the due date with specified quality features of the product.

B. How do you entertain the different product and order type?

- Robel

- As the production is hybrid strategy, we come across order from customer and stock often times with nearly equal urgency; however, the customer order gets priority nonetheless of the product design complexity, current time of production operation and status. In addition to this, the need to minimize board wastage comes as the second point of decision making to plan and schedule the job order. From this point on-ward, the production head is left with the majority of the operational decisions such as swapping process routing, assignment and sequencing operation on machines. Similarly, the design teams are by default set to align with the plan released from the planning department.

- Beza

- Additional point in Robel explanation, there is material availability check-up we do where we also check for the stock availability of the given job order product and determines the size or quantity to be released to the production process. Ofcourse, this is where the hybrid production strategy implementation helps our company to be the choice of our customers; this means the stock can be back-up to loosen up the due date complains as well as production floor shop need to quality compromising and increment of rework and/or scrap rate. Therefore, the customer is prioritized compared to the stock and due date comes as decision making driver then board wastage minimization consideration follows. For the case of product type, board wastage and setup time minimization are the conditions we take before making decision.

- Abdu

- If the job order release decision directly comes from planning, we try to communicate on the due date and order type then pass to the board wastage minimization point of consideration. In the meantime, the trend of order acceptance and release procedure alter and most of the time hinders the floor capacity to be utilized efficiently; it would have been easy and somehow more simple if there was consideration of the production floor status before developing plan and set delivery date- integrated scheduling limits the chance to consider the real time constraints regarding machine, manpower and buffer zone areas. At this point quality issues emerges now and then, set up time may not executed based on the sequence. On top of this, urgent sample order dives in to the production.

C. Is the operation static and/or dynamic?

- Robel

- The operation is dynamic as there are unforeseen events take place in the production floor shop as well as marketing department side. The production forecast is majorly depend on the marketing particularly for the stock item with fast moving but the customer order is emergent at some point of the time. For instance, rushed order, expedited order, design change after sample assembly test, due date extension, raw material starvation or buffer zone limitation, machine failure, tools replacement, setup time variation.

  - Abdu

- As an accepted fact, smooth production is unreal so production disruption is expected risk while dealing with machineries and also manpower. Hence, the fact that our production floor is job shop type with minor flexibility on the process sequence and routing of parts, the dynamic nature contributes more than 85% and possible to say it is dynamic by simply mentioning order arrival pattern, order and product type mixture and frequent need of setup for different machineries.

  - Andualem

- The operation is dynamic as the quality and sequence we do quality control varies from product to product and even change of time especially for the WIP parts there will be additional check list to do. In case of rush order, the degree of sensitivity for the quality parameters varies.

II. <u>Part Two/ Focus Group Discussion Session II- Production scheduling technique practiced</u>

A. Is production scheduling developed along with the planning or separately?

  - Mesfin

- The planning implicitly assumed to incorporate the production scheduling with given communication and/or from daily verbal report rounding the production floor. However the scheduling from planning and production perspective has different concept as the planning focuses on the due date, material optimization and machine utilization while the production focuses on single operation and its respective setup time and processing time decomposed level. This is mentioned as gap for why the plan and actual performance shows significant difference and the performance parameters not enough to measure the production performance. Therefore, the scheduling is integrated in the planning and production instead of as one controlling section while bridge the planning and production departments.

- Beza

- Planning schedules but as said by Mesfin its carried out from different perspective such as due date alignment, material starvation, board wastage minimization and scrap utilization efficiency and drawing releasing to the production floor. Ofcourse, it needs to be shared between the two departments and act like bridge where the decision is handled from sides where the planning can align with the marketing while production aligns with the resource and objective parameters optimization.

- Robel

- Well-explained, nothing to add here.

- Abdu

- Since, the operational level decision is majorly given to the production department, the schedule comes from the following concerns such as setup time, machine requirements, accumulated WIP, processing time while maintaining the basic such as board wastage minimization and customer priority or rush orders. In this trend the quality takes part in the production floor scheduling decision as the level of checking samples to be determined and the work load across the machines and respective remaining works to be done.

B. What are the criteria to dispatch mixed products; the dispatching rules used to prioritize jobs?

- Collective response | Abdu, Robel and Mesfin

- Since the decision making concerns are mentioned in one or another question, the dispatching rules aren't well compiled and subjected to frequent and well defined scenarios instead arises from knowledge and expertise understanding of the production system. Therefore these are the scheduling rules exercised.

Customer priority	Orders that come from customers gets the priority compared to stock order and even customer type and due date sensitivity
Board wastage minimization	Similar color and board type job order prioritized secondary level of priority.
Customer-Stock Blend	If either of these order can be blended due to similar family, product type
Due date	Based on the due date of the job order
Similar product family	Either identical or different product type but similar product family category such as kitchen or office
Machine requirement	The number of machines required to process the product and ship it to the packaging room
Total work remaining	The number of parts to be done for a given product

C. How do you measure the production floor performance; the performance parameters?

- Collective response | Abdu, Robel and Mesfin

- Based on the reports and respective key performance presented the production floor shop is subjected to the following performance measure:

    - Production volume and Scrap used Vs produced volume
    - No.of board used Vs produced products
    - Machine utilization- planned Vs actual
    - Downtime of machine
    - Due date delivery

D. Can you please mention how the dispatching rules and performance parameters are related for the aim the production floor work for?

- Abdu and Robel

- The quality is what the customer is willing to pay for and due date and alignment with the given specification are the performance parameter for the production floor and the customer priority and order blend dispatching rules corresponds to the production volume and due date often time scrap utilization; but the one to one function of the scheduling rules alignment doesn't hold true most of the time and the rule exercised let alone the parameters to be measured and evaluate the performance. Ofcourse, this shows the need for well-organized and defined scheduling rules based on the frequently emerging and nature of the production mode we find ourselves while managing the dynamic operation. In parallel to this, this can be input output relation to improve the planning, marketing and production operational flow along with the information and material to synchronize.

    - Mesfin

- Few points to mention/add here, the need to reconstruct the information plus material flow and operational procedure is to create alignment and corresponding input output node starting from the two extreme points of supply chain and marketing setting planning and production on parallel lane; hence, the scenarios can be clearly developed and close anticipation of the possible dynamic nature grasped and align the scheduling rules with the performance parameters identified and objectives to be optimized for better operational record.

III. Part Three/Focus Group Discussion Session III- Operational challenges; production scheduling implied

A. What do you think the production scheduling could solve the potential operational challenges here on the production floor?

- Abdu

- Clearly, we can manage the production disruption in a better way and respective performance parameters can be measured clear and exact, continuous improvements can be on-going process and machine as well as other raw material optimization increases. In this sense, the information flow synchronize across the horizontal departments and also better linkage with the planning and actual performance can be recorded. In depth to the production floor shop, setup time duration and frequency reduces, maximize the production volume while keeping board usage to the standard, due date can be met with minimum tardiness, less WIP accumulation, proper maintenance of the machineries, appropriate lead time of raw material supply and also WIP transfer from one work-station to the other.

- Bereket

- The planning and production department are the immediate connection nodes and both challenges and issues are reflected in same way to our department; nothing to add more.

- Beza and Robel

- Tangible documentation and reporting with detail data to pass to the decision, information from up to down and vice versa to develop feasible plan especially dealing with the BOM request preparation, quality standard labeling and due date setting, incorporate stock orders as contingency and overall harmonious and manageable operational flow at the manufacturing. Moreover, customize the acceptance and release policy and strategy and also amend the production scheduling rules as mitigation plan when unforeseen order dive in to the production floor while optimizing the parameters as prioritized by the company performance objective measure.

- Andualem

- The quality control can get better quality part output from each machines as the setup time and required tool set are in place and workload distribution can help to move WIP as quick s possible and reduce the tardiness period to be shipped to packaging, rework and scrap rate reduces considering the real-time status of the production floor. Constant quality checklist can be activated all the time and the assurance degree increases while dispatching to the customer.

B. Are the performance parameters mentioned in the research concept relate to the challenges identified in the existing system?

- Collective response | Abdu, Robel, Beza and Mesfin

- Yes they are and even though the labeled issues are not only subjected to the production scheduling gap and/or problem rather other contributing departments take part. In the case of production scheduling problem, the due date, machine requirement and total work remaining indirectly impacts the production volume, WIP accumulation %, completion time and tardiness to be managed; hence these can clearly give indication on the existing performance parameters and other departments improvement nodes.

C. What factors aggravate the operational challenges linked with the production scheduling and how?

- Abdu and Robel

- The very basic factor for the operational challenges during planning as well as production are the communication gap between manufacturing, stock and marketing department, defined policies on how to manage the stock and customer order based job orders arrival and due date setting and/or negotiation respectively. This can be reflected on the inconsistent dispatching rules and well-anticipated production scenarios. In addition to this, poor data recording and documentation left the manufacturing management across each department with surprise challenges and decision making difficulties more frequently. Similarly, the improvement areas become blurred or the staffs become factory problem blind as they get used to the nervous operational status.

- Mesfin and Andualem

- One last remaining concept which can be mentioned as aggravating factor is the lack to consider the current time of the production floor and real-time update to be released across each involving departments so that the job prioritization won't be centralized and left to the production perspective only rather shared responsibility. As the corresponding condition of the usual dispatching rules and the performance parameters, it can be taken as challenge to not have clear image of the gaps as well as potential improvement areas that require small effort or system installation on follow up and feed-back loop approach.

IV. Part Four/Focus Group Discussion Session IV- Proposed opinion; regarding production scheduling based issues

A. **Do you think that production scheduling addressed at every participating node of the whole system such as marketing to supply point?**

- Collective response | Abdu, Beza and Mesfin

- It was not designed that way, even the planning and production are doing scheduling on their own concept and objective setting and the backward integration and also the horizontal communication set off the scheduling to be majorly handled with the operational staff such as production, packaging and quality control department along the chain to confirm the specification and in-house quality standard. The rework section taking place is better way on how the scheduling needs to be devised and the participant staffs from each department can help to create end-to-end based scheduling content.

B. **What kind of dispatching rule do you propose to prioritize the list of jobs arriving to the production plant?**

- Abdu

- Personally, there is no specific scientific dispatching rule to be mentioned but the proposal I have is to start developing the dispatching rule from the production floor status and parallel decision with the planning and marketing department; this way the type of data we need to record and generate inference can be input for the improvement based decision and also come up with precise strategy incorporating short term to mid-term plan can be development.

- Mesfin and Robel

- As said, the scientific based dispatching rule needs to have well documented data using observation and across departments discussion like this; but to give some indication points, the prioritization rule needs to be distributed across each department specifically marketing, planning and production based on the common information flow loop while implicitly incorporating auxiliary side information coming from other departments such as supply and procurement and material management departments.

- Andualem

- The production mode of the current time needs to be articulated with the objective to optimize at that particular time and also along the process to compile the report; and in a way it clearly gives the content of the active operational challenges and performances measures.