Development of MS Excel and Power BI Integrated Production Scheduling System for an MSME

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Abstract. *Industry 4.0, or I4.0, uses digitalization, blockchain technology (BCT), artificial intelligence (AI), and machine learning (ML) to improve supply chain responsiveness and efficiency while cutting costs. Production planning (PP) is emphasized in manufacturing, a critical stage of supply chain management (SCM). In order to meet changing customer demands and optimize manufacturing processes, researchers concentrate on creating customized PP modules for use within enterprise resource planning (ERP) systems. ERP modules support predictive analytics for ideal inventory levels, resource needs, and supply chain risks in addition to managing operations. However, it is financially difficult for micro, small, and medium enterprises (MSMEs) to implement a comprehensive ERP system. Implementing ERP in MSMEs for production scheduling is challenging due to time, information technology (IT) expertise, and cost constraints, especially for make-to-order (MTO) MSMEs. Microsoft Excel (MS Excel) and Power BI offer a better alternative with easier learning, customization, quicker implementation, and lower cost. This solution integrates both for efficient production scheduling and resource planning. A concurrent, adaptable PP system that integrates MS Excel and Power BI is suggested as a solution to this problem. Machine schedules and important performance indicators are projected onto an operational dashboard by this system, which is intended for a parallel machine environment. The objective is to find the best combination of shifts (s = 1 to 3) and machines (m = 1 to 6) for a workload through 18 simulations, helping planners to meet delivery deadlines. The PP system's ideal combination changes over the course of six weeks of simulations, from 1s-1m to 3s-5m to 2s-3m, demonstrating its flexibility in response to shifting production demands. Despite fluctuating workload over six weeks, (i) 92% orders met the 45-day lead time, (ii) plant ran continuously for a month (100% achievement), and (iii) visibility for stakeholder was enhanced with efficient resource planning and providing scope for further detailed analysis towards improving important performance indicators.*

Keywords:

Enterprise resource planning (ERP), Micro, small and medium enterprises (MSME), Microsoft Excel (MS Excel), Power BI, Production planning (PP), Production scheduling

1. Introduction

Advanced planning and scheduling (APS) software offers planners a digital solution in the operations planning domain that is integrated with manufacturing execution systems (MES) and enterprise resource planning (ERP). Oracle NetSuite OneWorld, Microsoft Dynamics 365 Business Central (MSD365BC), and Systems Applications and Products in Data Processing (SAP) are popular ERP and MES systems available on the market. The APS's advanced planning module deals with the strategic planning of the plant, which includes labor, resources, and raw materials needed to meet customer demand [1]. The APS scheduling module facilitates decision-making regarding overtime, job prioritization, batch splitting, and determining the estimated date of job dispatch [2]. Utilizing machine learning (ML) and artificial intelligence (AI) algorithms, the APS generates optimal machine schedules that minimize costs and maximize resource utilization. Predictive analytics, which examines statistical and historical data, finds hidden patterns in it, and projects potential outcomes for various "What if" scenarios, is another way that the APS has benefited from its integration [3], [4].

After analyzing its particular requirements, financial constraints, and growth plans, every micro, small, and medium enterprise (MSME) considers implementing an ERP solution. Despite the benefits of popular ERP systems like SAP, MSD365BC, and Oracle NetSuite OneWorld, MSMEs may discover that these programs don't always match their particular requirements and goals, which may lead them to search for more appropriate and flexible alternatives [5]. An MSME must carefully consider its specific needs, financial situation, and expansion plans before choosing between an ERP-oriented and flexible scheduling system and standard ERP software such as SAP, MSD365BC, and Oracle NetSuite OneWorld. The ideal course of action will rely on the particular needs and goals of the MSME. Every choice has benefits. MSMEs may overcome many of the issues they face with manual or disjointed traditional systems and streamline their operations, boost productivity, and enhance data management with the aid of an adaptable and ERP-focused scheduling system. MSME's can leverage the advantages of a customized ERP-like system to position themselves for growth, enhanced competitiveness, and operational excellence [6]. A versatile and ERP-focused scheduling system is essential for MSMEs to effectively manage their resources, adapt to changing market demands, optimize operations, and set themselves up for growth in a competitive business environment. For MSMEs to succeed over the long run, it helps them to continue being flexible, effective, and customer-focused [7]-[9].

Power BI plays a crucial role in data visualization, particularly when interfacing with Microsoft Excel (MS Excel), despite being underutilized in scheduling environments [10]-[13]. A case study was carried out on a medium-sized metal manufacturer. They adopted a performance measurement system utilizing Power BI to transform Excel spreadsheets into visually appealing dashboards [11]. The use of AI, ML, blockchain technology (BCT), and digitalization in industry 4.0 (I4.0) facilitates creating ideal supply chains (SC), lowering costs, and increasing responsiveness. Production planning (PP) is crucial in the manufacturing phase of supply chain management (SCM). PP modules, standalone or integrated with customized ERP software, enable manufacturing facilities to operate efficiently to meet changing customer demand. Predictive analytics in ERP systems aids in forecasting ideal inventory levels, resource needs, and potential risks in SCM. While on-boarding for digitalization, to address the expense of implementing standard ERP software in case of an MSME, this paper focuses on developing an adaptable PP system for the task of production scheduling. The system has been developed using MS Excel, integrating it with Power BI, and displaying production scheduling scenarios through a dashboard.

Parallel production, sometimes referred to as parallel machine scheduling or parallel machine environment, is a method of setting up manufacturing processes in which several tasks are carried out concurrently on various machines. This method maximizes machine utilization and minimizes idle time to maximize production efficiency. In resource-constrained micro, small, and medium-sized businesses (MSMEs), parallel machine scheduling plays a critical role in increasing productivity and effectively satisfying customer demands. For a variety of reasons, MSMEs favor operating in parallel machine environments. First off, it shortens lead times for production, allowing for quicker product delivery to clients. It also improves flexibility in handling varying demand by dividing work among several machines. Thirdly, it lowers production costs by minimizing idle time and maximizing resource utilization. Parallel machine scheduling also increases total production throughput, which enables MSMEs to successfully compete in the market while upholding quality standards. As a result, MSMEs can improve productivity, streamline processes, and maintain their competitiveness in fast-paced business environments by implementing parallel machine environments [14]-[17].

A PP system with production scheduling task designed for a parallel machine environment is discussed in the paper with a special reference to an MSME. The PP system proposes number of shifts (s) and number of machines (m) schedules as a result. Further for a given set of inputs made available through user input sheet (UIS), it highlights potential key performance metrics on an operational dashboard. In order to have job readiness before the committed delivery due date, the entire parallel machine scenario is simulated for 18 combinations of s and m on weekly basis to obtain the best possible s and m planning for the forthcoming weeks. The entire system is made user friendly and dynamic in nature which would help the planner to get latest results. The scenario discussed in this paper is best suitable for a MSME looking to remain operational for an extended period of minimum one month with at least one shift per day. The main objective of system is to give an optimal combination of s to be planned and m to be used to complete given production plan within next one and half month. The operational dashboard has the purpose of highlighting order status, due date performance, machine downtime, shift planning, machine planning, overall equipment effectiveness (OEE) which gives a complete visualization of parallel machine scheduling problem. Weekly simulations were executed for six weeks and it was found that the PP was checked against *1s* planning to *3s* planning with m = 1 to 6, based on the workload present in that particular week.

The following are important contributions and findings of the work:

1. Development of adaptable PP system for scheduling using MS Excel.
2. Integration of MS Excel based module with Power BI.
3. Visualization of the key performance metrics of scheduling environment to stakeholders through the Power BI operational dashboard.
4. Scheduling analysis of parallel machine environment is done for job shop MSME.
5. The developed adaptable PP system for scheduling has been analysed by mini APS simulation and validated

by proposing or projecting machine schedules and obtaining optimum *s* and *m*.

The paper is organized as follows: Section 2, related work, discusses the literature review related to types of scheduling problems, parallel machine scheduling environment for MSMEs. It also discusses scheduling problems in APS software. Further it reviews MS Excel and Power BI integrated scheduling systems for MSMEs. The section 3, materials and methods, presents assumptions and life cycle of an order. The framework subsection, highlights detailed information on framework used while developing an ERP compliant adaptable scheduling system. Section 4, results and discussion, gives results obtained by performing weekly simulations for six weeks where each simulation has 18 iterations for various combination of *s* and *m*. It also presents the details about downtime, OEE, and information about order related KPIs. This section also highlights the discussions and findings obtained around the results. Finally concluding remarks, scalability and sustainability of the current study, academic contributions and scope for future work are presented in section 5, conclusion.

2. Related Work

Manufacturing activity is one of the important components in SCM. PP is essential at this stage, and as a result, it is also a critical contributor in efficient functioning of the SC. This criticality of PP in SCM has got a great attention from researchers and engineers to develop customized PP modules either standalone or integrated with their organization's existing ERP software modules. It is expensive for MSMEs to implement standard ERP software. With all these due considerations an adaptable and ERP compliant scheduling system for parallel machine environment is being presented in this paper. To develop a customized PP module for scheduling it is necessary to have clear understanding of various aspects of scheduling in PP. With this approach, the literature review has been carried out with different sub-sections highlighting types of scheduling problems, parallel machine scheduling environment, scheduling problems attempted using APS software, and MS Excel and Power BI integrated scheduling system for MSMEs.

The literature review on scheduling problem types and the parallel machine scheduling environment for MSMEs is covered in this section. It also covers issues with scheduling in the APS program. It also examines integrated scheduling systems for MSMEs using Power BI and MS Excel.

A. Types of Scheduling Problems

Sequencing and Scheduling are the fundamental activities for planning department in a manufacturing plant and service industry. Sequencing is the order in which jobs are processed over machines. Scheduling is defined as “the allocation of resources over time to perform a collection of tasks” [18]. It is also “a process of organizing, choosing, and timing resource usage to carry out all tasks required for generating required outputs at particular time satisfying all the constraints and relations among tasks and resources” [19]. There are various scenarios of scheduling problem such as single machine job shop, flow machine job shop, assembly job shop, hybrid job shop, hybrid assembly shop, open shop, and closed shop. Scheduling problem can be categorized as deterministic, static, dynamic, and stochastic depending upon nature of job’s arrival [20]. One of the most commonly observed scheduling environment in industries is parallel machine scheduling environment. Parallel machines can be defined as same kind of machines having similar configuration, setup and features and are available at one place with number of jobs arriving for operation at different times [21]. *Figure 1* shows the parallel machine environment where J1, J2, J3, J4, and J5 are the jobs arriving for operations at times t1, t2, t3, t4, and t5 respectively over machines M/C-1, M/C-2, M/C-3, M/C-4 and M/C-5. The assignment of jobs on machine is carried out on first-come-first-serve (FCFS) basis. In real life cases parallel machine environment can be seen in process layout in which machines performing same operations are grouped in one department. Such type of scheduling environment results in high degree of machine utilization as one single machine is not booked for a single job [22].

B. Parallel Machine Scheduling Environment

Parallel machine scheduling problem can be dealt by having minimization of total weighted completion time as its objective function [23]. Complex scheduling problems can be solved with the techniques such as dynamic programming, branch and bound, mixed integer programming and approximation procedures in supply chain scheduling [24]. A parallel machine environment can be such in which not all machines are compatible for all jobs. This is a scenario in semiconductor industry where if the processing time between two consecutive jobs exceeds a time limit then the machine gets disqualified for operation thus making it unavailable machine for that particular operation. Integer linear programming and constraint programming techniques are used to solve such problem [25].

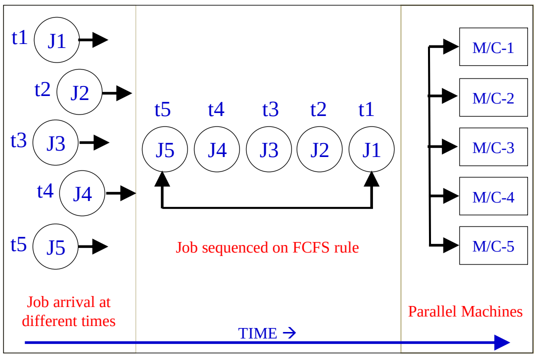

Fig. 1 Representation of Parallel Machine Environment

A parallel machine environment can have objective to minimize total weighted tardiness and considers different combinations of machine and job correlations. For such case branch and bound algorithm becomes more complicated when number of machine correlations and job correlation increases [26]. An analytical system was also proposed which gives different rescheduling performance strategies and quantification of these performance measures [27]. A parallel scheduling problem with mold constraints had also been studied. It describes a scenario in which two or more jobs with same mold requirements cannot be loaded on same or different machines making it a resource constraint. They have developed a mathematical system which minimizes make span time satisfying the mold constraint in the parallel machine scheduling environment [28]. A parallel machine scheduling problem had also been studied which considers machine disruptions. It deteriorated jobs as actual processing time of jobs increased when scheduled with overtime machine usage. It decreased the machine efficiency and scheduling performance as well [29].

C. Scheduling Problems in APS Software

Researchers have worked to integrate various scheduling problems in the APS software and making it closer with real time scenarios. A case study had been addressed in which authors have simulated a parallel machine environment in APS software considering due dates of jobs, job sequencing and capacity constraints in the plant. The objective of the work was to minimize operational cost of machine idling and inventory holding cost **[30]**. The role of production scheduling and scheduling problems which needs to be addressed by production planning and control (PPC) department while implementing the APS on the shop floor were elaborated. A solid conceptual foundation for APS systems was presented for use as a guide [31]. The parallel machine scheduling problems were solved with the help of mathematical programming and Meta heuristics. Different scheduling scenarios were simulated before generating the optimum machine schedule [32]. Finding optimal number of resources was addressed in parallel machine scheduling environment by taking into consideration resources capacity, precedence constraints and workload balance [33].

D. MS Excel and Power BI Integrated Scheduling System for MSMEs

The development of APS software has various features in it which are very specific to certain constraints and may not give desired results when implemented in different scenarios. MS Excel being versatile and user friendly tool, has been found advantageous to overcome scenarios which can’t be captured in APS software. The use of spreadsheets and MS Excel over the ERP and APS software and its ease to planner for decision making in operations planning and scheduling were discussed. Three cases were discussed where the use of APS software had resulted in unsatisfactory solutions for PPC department. The first case was of Norwegian cheese producer who had a requirement of scheduling orders based on production capacities. In this case the MS Excel solution had easy visualization and acceptance from planners. The second case was of make-to-stock (MTS) plant which had capacity restrictions and MS Excel solution was easy to understand and reliable rather than APS, as the results of APS deviated from the original solution. The third case demonstrated was of make-to-order (MTO) plant where meeting of delivery date was very strict and the APS software deviated from the actual delivery date making APS lesser reliable for planners [34]. The APS and ERP implementation challenges that are faced by Micro, Small and Medium Enterprise (MSME) were addressed. A cause and effect diagram of failure of ERP implementation in a company was reported. The major reason for this was over budgeting, absence of project management practices, inaccurate data, and complexity of software and lastly software did not meet the business processes [35]. The critical challenges faced by Canadian oil and gas industry for implementing the APS were reported. The major challenges were difficulty in understanding the complexity of software by project teams, interface issues, improper testing, people’s resistance to change, non-clarity of leadership, and excessive customization leading to sub optimal solutions [36].

A case study was conducted on a medium-sized metal manufacturer. They implemented a performance measurement system using Power BI to convert Excel worksheets into visually attractive dashboards [11]. A Power BI dashboard was created using research data from Ly Foods Ltd. The study presents a live Microsoft Power BI dashboard using the ADR (Action Design Research) method, aimed at improving supply chain management (SCM) practices with advanced technologies. The dashboard showed key performance indicators (KPIs) like inventory turnover, order cycle time, order status, order quantity, product ranking by sales, sales by product, and sales by country. It also highlighted the underperforming KPIs that contributed to the overall low performance of the supply chain at Ly Foods [12]. A production dashboard was created using Power BI for a pharmaceutical company. It showed key performance indicators like operational availability rate (OAR), quality rate (QR), overall equipment efficiency (OEE), and overall operations effectiveness (OOE). This dashboard was designed for the production manager to suggest investments. Management would review these proposals annually [13].

Based on the literature survey it is understood that there is need of a robust and reliable MS Excel and Power BI integrated scheduling system for MSMEs. For MSMEs the processes are complicated and implementing APS and ERP is found economically challenging. The APS and ERP implementation may result in exceeding the financial budget of the plant with no clarity on the expectation of return on investment. MS Excel being user friendly tool, it is quite easy to build a customized and adaptable scheduling system according to requirements and aligning the machine schedules with real time scenarios. In this paper an MS Excel and Power Integrated planning and scheduling system has been discussed for parallel machine scheduling environment. The industries considered are tier 2 and tier 3 suppliers in SC. Though the scope of work has been limited only for parallel machine scheduling problem as parallel machines scenario is most common in MSMEs, the proposed methodology can be adapted and examined for different scenarios of machine scheduling.

3. Materials and Methods

This study is carried out by focusing on a MSME that is involved in job-shop production. The number of orders received, process planning, operation times, machine downtimes, *s*, and *m* are some of the factors included while preparing production schedule. MS Excel has been used to do PP and thereby scheduling. MS Excel based PP system receives some user inputs through UIS, performs some analysis of data and is further interfaced with Power BI. Power BI displays the operational dashboard for stakeholders and assist in decision making in selecting a proper combination of *s* and *m* to meet the committed delivery due date.

This section deals with various assumptions being made, and provides detailed information on framework used while developing an adaptable scheduling system. The framework is further explained in relation to requirements of various user inputs, sequencing strategy, and machine allocation method considering different scenarios.

A. Assumptions

There were some assumptions made while developing the fundamental scheduling system.

1. All machines are capable to perform all the operations to covert the raw material into finished good.
2. For each batch lot all the operations, required to convert raw material into finished good, are performed on a single machine. Only thing is that the sequence of operations and their respective operation timings varies from one batch lot to other batch lot.
3. Any batch lot of repetitive order type though placed with a certain time gap (may be after weeks/months) would save only time of process planning engineer in determining the processing times.
4. The resource nature is compatible for batch operation i.e. once the batch is loaded on machine, it completes its whole batch operation and then is available for next batch operation.
5. After completion of current operation the batch lot is moved to finished goods section.
6. All resources are initially free i.e. no batch is loaded at time zero.
7. The batch arrival date and time are as per the order placed.
8. Setup time for batch is negligible and doesn’t affect the output of a machine.
9. Each batch will process on any of the available machine and no re-allocation is allowed.
10. All jobs as per the orders are independent and are available for processing from the arrival time.
11. The scheduling activity is run at the time of commencement of first shift per week based on the orders accumulated by that time.
12. The downtime occurrence of machines are ignored. However, the delay in processing of subsequent jobs are updated prior to scheduling.
13. Emergency orders or prioritization of orders is not considered.
14. This scheduling analysis is for six machines only.
15. Overall lead time of all jobs is maximum 45 days i.e. around 6 weeks (order accumulation - 1 week + cycle time or processing time determination - 1 week + manufacturing lead time (MLT) - 4 weeks). For example, order placed on week 4 is required to be completed with production by week 10 (week 4 + 6 weeks overall lead time).

B. Life Cycle of an Order

An order corresponds to order received by sales team and communicated to the PP team. Planning team receives codes for tracking and traceability purpose which has details such as job code, batch number, batch arrival week, batch arrival date, batch arrival time and quantity. For the scheduling environment simulated in this paper, the average lead time for the order is considered as 45 days. The paper discusses a case where the orders are to be completed under period of 45 days from its entry by the sales team. *Table 1* shows fifteen orders that are entered by sales team in the week 4 through UIS 1.

After the orders are punched in week ‘n’ in UIS 1, the next step is cycle time study of the batches and fixing the cycle time of a single job quantity per batch for production. For instance, let's consider a general-purpose lathe machine. Drawing from previous experiences, documented historical process data sheets, and expert insights, the process planning engineer meticulously crafts the process plan. This plan entails mapping out the sequence of operations required for a specific job throughout the entire order. Every decision is grounded in precise calculations concerning essential processing parameters such as cutting speed (*S*, mm/min), feed rate (*f*, mm/revolution), depth of cut (mm), number of passes (*n*) and taper turning settings. Consequently, factors like set up time, tool change time, tool positioning time, and material handling time are thoughtfully factored in when determining the overall cycle time. This entire activity is done in week ‘n+1’. *Table 2* shows the cycle times entered by process planning engineer in week 5 through UIS 2.

Table 1 Orders entered by sales team in week 4 (‘n’) in UIS 1

Sr. No.	Job Code	Batch Number	Batch Arrival Week Number	Batch Arrival Date	Batch Arrival Time	Quantity
1	J2803231	B1	Week 4	28 March-23	14:23	380
2	J2903231	B2	Week 4	29 March-23	16:05	400
3	J2803232	B3	Week 4	28 March-23	11:00	400
4	J2903232	B4	Week 4	29 March-23	09:30	400
5	J3003231	B5	Week 4	30 March-23	11:21	400
6	J3003232	B6	Week 4	30 March-23	12:09	250
7	J3103231	B7	Week 4	31 March-23	13:10	600
8	J0104231	B8	Week 4	01 April-23	11:07	400
9	J0104232	B9	Week 4	01 April-23	09:35	300
10	J3103232	B10	Week 4	31 March-23	17:13	200
11	J2903233	B11	Week 4	29 March-23	15:21	200
12	J3003233	B12	Week 4	30 March-23	14:23	340
13	J3103233	B13	Week 4	31 March-23	10:21	290
14	J0204231	B14	Week 4	02 April-23	09:44	280
15	J0104233	B15	Week 4	01 April-23	10:44	260

A sample cycle time calculation has been explained with reference to *Table 2*; Row 5 for Job Code - J3003231; Batch Number - B5. Suppose the machine is run with S = 50 mm/min; f = 1 mm/revolution. Number of passes required = 2, and the length of material to be cut is 200 mm. Then cutting time (T_{cut}; min) calculated using equation 1 comes as 8 min.

$$T_{cut} = \left(\frac{L}{S \times f}\right) \times n \tag{1}$$

Non-cutting time is the summation of set up time, tool change time, tool positioning time, and material handling time. For this sample, the non-cutting time comes out to be 7 minutes by adding up all the applicable component times (set up time, tool change time, tool positioning time, and material handling time). Thus, cycle time in minutes is the summation of cutting time and non-cutting time i.e. (8+7); which adds up to 15 minutes as mentioned in table 2 for job B5.

Table 2 Cycle time entry during week 5 (‘n+1’) by process planning engineer for orders received in week 4 (‘n’).

Sr. No.	Job Code	Batch Number	Cycle Time in Minutes
1	J2803231	B1	11
2	J2903231	B2	12
3	J2803232	B3	13
4	J2903232	B4	14
5	J3003231	B5	15
6	J3003232	B6	15
7	J3103231	B7	15
8	J0104231	B8	15
9	J0104232	B9	15
10	J3103232	B10	15
11	J2903233	B11	11
12	J3003233	B12	16
13	J3103233	B13	16
14	J0204231	B14	16
15	J0104233	B15	16

Once the cycle time has been determined and updated by the process planning engineer, they start the production in week “n+2” and they have to complete the production within next 4 weeks. Thus, the shift and machine planning should be done by system in such a way that the parts are ready in week “n+6”, thereby achieving the committed delivery due date. *Figure 2* provides the insights on the lifecycle of an order entered by sales team

C. Framework

Figure 3 shows the framework of the system and is divided into 6 phases. Phase 1 starts with UISs (UIS 1, UIS 2, UIS 3). Phase 2 performs sequencing of arrived jobs as per the orders. Phase 3 includes algorithm execution which stimulates the scenario for 18 iterations of shifts and machine combinations. The algorithm results in projecting machine schedules for one shift planning, two shift planning and three shift planning. Phase 4 contains the machine booking which is a result of machine allocation. Phase 5 contains the iteration summary which summarizes the entire simulated scenario and gives the best possible result. Phase 6 has integration of Power BI and MS Excel which displays the planned versus actual on the operational dashboard where the actual inputs are to be given by user through UIS 4 and UIS 5.

Phase 1 to phase 5 are executed with the help of MS Excel and phase 6 with the help of Power BI. All information is gathered by manual inputs from the respective responsible authorized persons only. This needs continuous observation of activities being executed at various phases. The phase 1, phase 3 and phase 4 have scope to get integrated with the existing ERP software. The direct information exchange can be integrated between this adaptable MS Excel based mini APS and existing ERP software modules.

User Inputs

User has to input the detailed information pertaining to sales order batches as shown in *Table 3*.

Ranking and Sequencing

Sequencing is defined as “arranging the batch in a particular order” [37]. The Ranking of the orders is done on FCFS basis. The orders that have been arrived first are given priority over the orders which are arrived later. *Table 4* shows the ranking given to work orders. It can be seen in *table 4* that work order arrived on 28 Mar 11:00 (Row3) has been ranked 1 and work order arrived on same day 28 Mar 14:23 (Row1) has ranked 2. The randomization in entry is due to the orders entered by different sales team members from different locations. For any collected order, the sales team members are required to enter the order details before Sunday 23:00 hrs with their actual order date and time details. Monday 07:00 hrs to Sunday 23:00 hrs of the week is considered as order accumulation and aggregation period for a week under consideration. After the ranking has been given to orders, the sequencing or orders is done by PP system in order to have a priority of work orders to be executed in scheduling scenario. *Table 5* shows the sequencing done for orders received and accumulated or aggregated in week 4.

When assessing workload, the initial step involves evaluating the order quantity per batch. Subsequently, the cycle time of a particular job for the respective batch, as outlined by the production planning engineer in Table 2, is taken into account. Multiplying the cycle time (measured in minutes) of a specific job by the corresponding order quantity per batch facilitates the determination of the workload in minutes. Further division of this figure by 60 provides the workload in hours for the specific batch. The workload in hours for batch completion is calculated by formulae given by Rauchecker and Schryen [38].

$$\text{Workload in hours} = \frac{\text{Batch quantity} \times \text{Cycle time (minutes)}}{60} \quad (2)$$

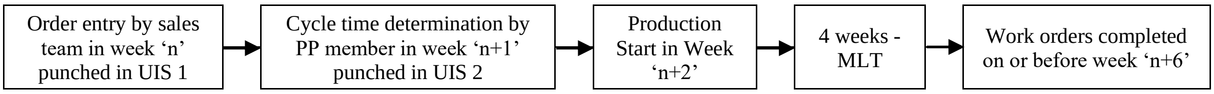

Fig. 2 Life cycle of an order entered by sales team

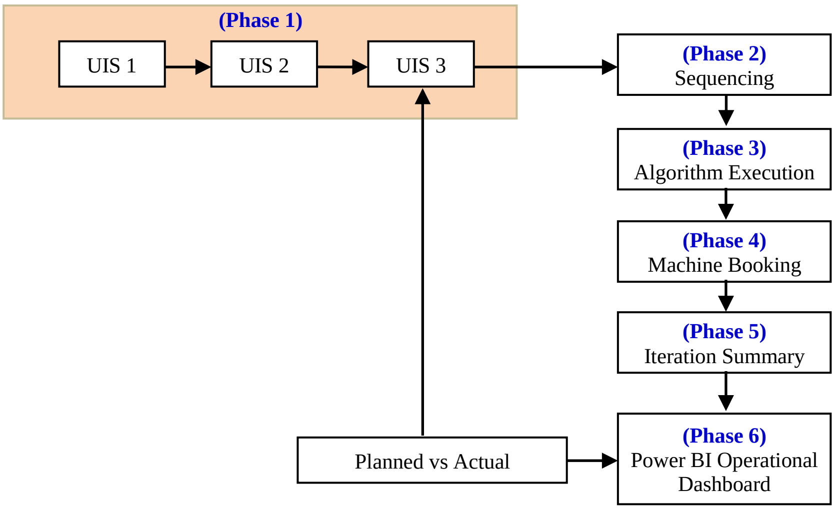

Fig. 3 Framework of MS Excel and Power BI integrated scheduling system.

Table 3 User input sheets with parameters and their significance

User Input Sheet	Inputs Required from User	Remarks
UIS 1	Details of sales orders which are to be released for production from planning team - Job code, Batch no., Week no., Batch arrival date, Batch arrival time, Quantity and start date of week are to be punched by sales team user in UIS 1.	The whole activity of punching the sales orders of week 'n' in UIS 1 is done by sales order team members in between period of Monday 07:00 hrs to Sunday 23:00 hrs of the week 'n'.
UIS 2	Operation or Cycle time in minutes	The Cycle time study is done by process planning engineer and the operation or cycle times of work orders of week 'n' need to be punched in UIS 2 in between period of Monday 07:00 hrs to Sunday 23:00 hrs of the week 'n + 1'.
UIS 3	Machine available date and machine available time	The planner must enter the actual machine availability at the end of week 'n+1' taken from planned versus actual sheet before releasing the production schedule for production in week 'n+2'.
Planned versus actual	Actual start date and time, Actual end date and time, Machine downtime hours, Breakdown hours	In order to capture the delays in timeline of production orders, planner needs to take a review of entered details. This entry is done on daily basis as the work orders are completed.

Table 4 Ranking of orders received and accumulated or aggregated in week 4

Sr. No.	Job Code	Batch Number	Batch Arrival Week Number	Batch Arrival Date	Batch Arrival Time	Quantity	Rank
1	J2803231	B1	Week 4	28 March-23	14:23	380	2
2	J2903231	B2	Week 4	29 March-23	16:05	400	5
3	J2803232	B3	Week 4	28 March-23	11:00	400	1
4	J2903232	B4	Week 4	29 March-23	09:30	400	3
5	J3003231	B5	Week 4	30 March-23	11:21	400	6
6	J3003232	B6	Week 4	30 March-23	12:09	250	7
7	J3103231	B7	Week 4	31 March-23	13:10	600	10
8	J0104231	B8	Week 4	01 April-23	11:07	400	14
9	J0104232	B9	Week 4	01 April-23	09:35	300	12
10	J3103232	B10	Week 4	31 March-23	17:13	200	11
11	J2903233	B11	Week 4	29 March-23	15:21	200	4
12	J3003233	B12	Week 4	30 March-23	14:23	340	8
13	J3103233	B13	Week 4	31 March-23	10:21	290	9
14	J0204231	B14	Week 4	02 April-23	09:44	280	15
15	J0104233	B15	Week 4	01 April-23	10:44	260	13

Table 5 Sequencing of orders received and accumulated or aggregated in week 4

Rank	Job Code	Batch Number	Batch Arrival Week Number	Batch Arrival Date	Batch Arrival Time	Quantity	Cycle Time in Minutes	Workload in Minutes	Workload in Hours
1	J2803232	B3	Week 4	28 March-23	11:00	400	13	5200	86.7
2	J2803231	B1	Week 4	28 March-23	14:23	380	11	4180	69.7
3	J2903232	B4	Week 4	29 March-23	09:30	400	14	5600	93.3
4	J2903233	B11	Week 4	29 March-23	15:21	200	11	2200	36.7
5	J2903231	B2	Week 4	29 March-23	16:05	400	12	4800	80.0
6	J3003231	B5	Week 4	30 March-23	11:21	400	15	6000	100.0
7	J3003232	B6	Week 4	30 March-23	12:09	250	15	3750	62.5
8	J3003233	B12	Week 4	30 March-23	14:23	340	16	5440	90.7
9	J3103233	B13	Week 4	31 March-23	10:21	290	16	4640	77.3
10	J3103231	B7	Week 4	31 March-23	13:10	600	15	9000	150.0
11	J3103232	B10	Week 4	31 March-23	17:13	200	15	3000	50.0
12	J0104232	B9	Week 4	01 April-23	09:35	300	15	4500	75.0
13	J0104233	B15	Week 4	01 April-23	10:44	260	16	4160	69.3
14	J0104231	B8	Week 4	01 April-23	11:07	400	15	6000	100.0
15	J0204231	B14	Week 4	02 April-23	09:44	280	16	4480	74.7

In Table 5, consider row 5 of job J2903231 with batch B2 having a cycle time of 12 minutes and batch quantity of 400 pieces. Thus, the total workload in hours = (400 × 12)/60 =80 hours. Thus, it will take 80 hours to complete the entire batch of J2903231 of 400 pieces. The sequencing and cycle time calculations of all orders that have been aggregated in week 4 is done by the process engineer and PP team between Sunday 23:00 hrs to Monday 7:00 hrs of entire week 5, so that the production of orders received during week 4 can be started by commencement of week 6, i.e., Monday 7:00 hrs.

Algorithm Execution

During the week 5 (‘n+1’) itself, the entire PP system simulates 18 iterations where each iteration corresponds to a combination of shifts and machines. For example - production planned on 1s-2m, 2s-3m and so on. The orders are allocated on machines based on their availability using FCFS approach. *Table 6* shows the machine schedule obtained for all the orders aggregated in week 4 where the production is planned for 3 shifts on 5 machines. It can be seen that order J3103233 (Row 9) was allocated on machine no. 2, as machine 2 was available at earliest 01-May 17:10 (Row 8) among the others. Also, the batches are completed as per the overall lead time of 6 weeks (week 4 + 6 = week 10) by planning for 3 shifts and 5 machines during week 6 through week 9.

Iteration Summary

Once all the 18 iterations are carried out, a summary report is generated. The summary report highlights which possible combination of shift and machines should be planned in order to complete the production of all orders in hand to achieve the committed delivery due date. *Figure 4* shows the iteration summary for work orders that have come in week 4 and will be released for production by planning for 3 shifts on 5 Machines. The planner has a facility to enter a tolerance or buffer days by taking customer due date or committed delivery due date as its reference. It can be seen that by running the plant on 1 shift and 2 shift the customer due date of 8th May is not achieved as the work orders exceeds its readiness beyond the committed delivery due date (Yellow Highlighted).

It can be seen that the plant can complete the production before the customer due date if the plant is planned on 2 shifts on 6 machines OR 3 shifts on 5 machines (Green Highlighted). Also, the plant runs in under capacity if planned on 3 shifts on 6 machines (Red Highlighted). Planning with 3 shifts on 6 machines will make the job ready too much early which is not accepted as this will be led to plant shutdown for further period. As its MSME, it’s economical for them if they have workload for 1 month period from the date of planning the schedule. *Figure 5* shows Gantt charts for the visualization of entire iteration summary in the “Machine Booking” sheet.

Table 6 Machine schedule of 3 shift 5 machine plan for week 4 work orders

Rank	Job Code	Batch Number	Quantity	Cycle Time in Minutes	Workload in Minutes	Machine Allocated	Start Date	End Date	Batch Completion Week	M/C-1	M/C-2	M/C-3	M/C-4	M/C-5
1	J2803232	B3	400	13	5200	1	01-May 19:10	04-May 9:50	Week 9	04-May 9:50	01-May 17:10	02-May 12:00	01-May 18:00	11-April 7:00
2	J2803231	B1	380	11	4180	5	11-April 7:00	13-April 4:40	Week 6	04-May 9:50	01-May 17:10	02-May 12:00	01-May 18:00	14-April 4:40
3	J2903232	B4	400	14	5600	5	14-April 4:40	17-April 2:00	Week 7	04-May 9:50	01-May 17:10	02-May 12:00	01-May 18:00	18-April 2:00
4	J2903233	B11	200	11	2200	5	18-April 2:00	19-April 14:40	Week 7	04-May 9:50	01-May 17:10	02-May 12:00	01-May 18:00	19-April 14:40
5	J2903231	B2	400	12	4800	5	19-April 14:40	22-April 22:40	Week 7	04-May 9:50	01-May 17:10	02-May 12:00	01-May 18:00	22-April 22:40
6	J3003231	B5	400	15	6000	5	22-April 22:40	26-April 2:40	Week 8	04-May 9:50	01-May 17:10	02-May 12:00	01-May 18:00	27-April 2:40
7	J3003232	B6	250	15	3750	5	27-April 2:40	29-April 17:10	Week 8	04-May 9:50	01-May 17:10	02-May 12:00	01-May 18:00	29-April 17:10
8	J3003233	B12	340	16	5440	5	29-April 17:10	03-May 11:50	Week 9	04-May 9:50	01-May 17:10	02-May 12:00	01-May 18:00	03-May 11:50
9	J3103233	B13	290	16	4640	2	01-May 17:10	04-May 22:30	Week 9	04-May 9:50	04-May 22:30	02-May 12:00	01-May 18:00	03-May 11:50
10	J3103231	B7	600	15	9000	4	01-May 18:00	08-May 0:00	Week 9	04-May 9:50	04-May 22:30	02-May 12:00	08-May 0:00	03-May 11:50
11	J3103232	B10	200	15	3000	3	02-May 12:00	04-May 14:00	Week 9	04-May 9:50	04-May 22:30	04-May 14:00	08-May 0:00	03-May 11:50
12	J0104232	B9	300	15	4500	5	03-May 11:50	06-May 14:50	Week 9	04-May 9:50	04-May 22:30	04-May 14:00	08-May 0:00	06-May 14:50
13	J0104233	B15	260	16	4160	1	04-May 9:50	07-May 7:10	Week 9	07-May 7:10	04-May 22:30	04-May 14:00	08-May 0:00	06-May 14:50
14	J0104231	B8	400	15	6000	3	04-May 14:00	08-May 18:00	Week 10	07-May 7:10	04-May 22:30	08-May 18:00	08-May 0:00	06-May 14:50
15	J0204231	B14	280	16	4480	2	04-May 22:30	07-May 1:10	Week 9	07-May 7:10	08-May 1:10	08-May 18:00	08-May 0:00	06-May 14:50

Customer due date		08 May-23	Shift Start time	7:00					
No of Shifts Planned	Shift End Time = Deadline Time	No of machines Planned	Projected machine free date for given workload						Overtime Needed per day (Hrs)
			1	2	3	4	5	6	
1	3:00:00 PM	1	01 October-23 11:00						2604.4
		2	17 July-23 12:40	15 July-23 7:30					2467.0
		3	16 June-23 11:50	23 June-23 14:20	23 June-23 14:00				2371.5
		4	06 June-23 14:20	11 June-23 8:50	04 June-23 11:20	13 June-23 7:40			2271.5
		5	30 May-23 7:50	31 May-23 7:10	29 May-23 10:30	24 May-23 9:00	25 May-23 14:40		1791.5
		6	20 May-23 7:10	19 May-23 10:40	24 May-23 13:20	13 May-23 12:40	22 May-23 10:00	21 May-23 10:20	1311.5
2	11:00:00 PM	1	15 July-23 19:00						2444.4
		2	08 June-23 20:40	07 June-23 15:30					2218.1
		3	24 May-23 11:50	27 May-23 22:20	28 May-23 14:00				2015.9
		4	19 May-23 14:20	21 May-23 16:50	18 May-23 19:20	22 May-23 15:40			1791.5
		5	10 May-23 20:50	13 May-23 12:20	11 May-23 14:40	13 May-23 16:40	14 May-23 8:40		831.5
		6	06 May-23 9:50	06 May-23 12:10	08 May-23 16:00	06 May-23 7:20	08 May-23 22:00	08 May-23 12:50	No Overtime Needed
3	7:00:00 AM	1	20 June-23 11:00						2302.2
		2	26 May-23 2:30	27 May-23 1:40					1951.5
		3	19 May-23 11:10	16 May-23 16:50	19 May-23 12:10				1642.6
		4	14 May-23 19:50	13 May-23 8:00	13 May-23 14:40	15 May-23 15:40			1293.7
		5	07 May-23 7:10	08 May-23 1:10	08 May-23 18:00	08 May-23 0:00	06 May-23 14:50		No Overtime Needed
		6	04 May-23 9:50	04 May-23 19:50	02 May-23 12:00	01 May-23 18:00	04 May-23 2:00	02 May-23 10:30	No Overtime Needed

Colour scheme

- (green) **With in Tolerance**
- (orange) **Under Tolernace - Under capacity**
- (yellow) **Outside Tolerance - Over capacity**

RESULT	Plan 3 Shifts on 5 Machines with an overtime of 0 Mins per day so as to meet the deadline for the given workload

Fig. 4 Iteration summary for work orders of week 4

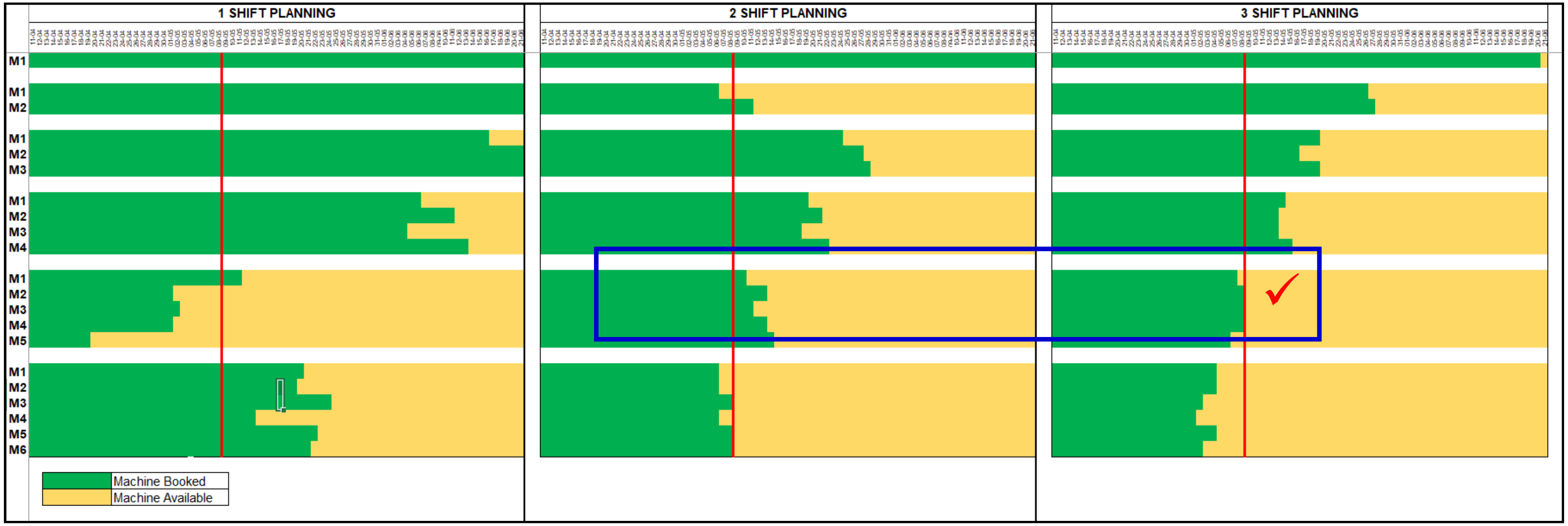

Fig. 5 Visualization of machine booking for orders aggregated during week 4

Note: The iteration summary of 18 iterations shown in figure 4 is visualized as machine booking Gantt Charts in this figure 5.
As the customer due date is achieved (all green bars are just within vertical red color line), the planning scenario of 3 shifts 5 machines is recommended over 2 shifts 5 machines.

It represents how close or far is the machine booking from the committed delivery due date or customer due date. As the simulation happens for 18 iterations the entire simulation can be visualized by this sheet. The red line represents the due date before which we have to complete the orders The green colour indicates that that the machines are booked for those days. The yellow colour indicates that the machines are free and available. In the Gantt charts shown in *figure 5*, the more is the green bar close to red line shows that the work orders can be completed ON TIME thus achieving the timely delivery of jobs. The more the green bars cross the red line it show the delay off days that might occur if we plan the shifts and machines with that combination. For example, in the *figure 5*, if we plan the production for the orders of week 4 with 1 shift on 5 machines it is seen that the there is too much delay in the job readiness. So such a combination of shift and machines is not recommended. On the other side, it is seen that by running the plant with 3 shifts planned on 5 machines gives the job readiness ON TIME. Also note that planning on 3 shifts on 6 machines will result in too early readiness of jobs which is not economical for MSME as they have to run the facility for at least 1 month.

Consider the planning scenario of 2 shifts 5 machines. It is clearly seen in *figure 4* (Iteration summary) that all the 5 machines -M/C-1 (10 May 20:50) , M/C-2 (13 May 12:00),M/C-3 (11 May 14:40),M/C-4 (13 May 16:40),M/C-5 (14 May 8:40) are getting free (completing plan) after customer due date (8 May 23:59). This can be seen in *figure 5* with the green bars of machine booking hours crossing the red line of customer due date. So, this planning of 2 shifts 5 machines is not recommended as it will fail to meet the customer due date.

On the other part, consider the planning scenario of 3 shifts 5 machines. We can see in *figure 4* that all the 5 machines - M/C-1 (7 May 7:10), M/C-2 (8 May 1:10), M/C-3 (8 May 18:00), M/C-4 (8 May 0:00), M/C-5 (6 May 14:50) are getting free (completing plan) before customer due date (8 May 23:59). This plot is seen in *figure 5* where the green bars of machine booking hours are just touching the red line which represents customer due date. So, this planning is recommended as the customer due date is achieved.

MS Excel - Power BI Integration

In order to have a visual representation of the entire planning system, a Power BI dashboard was developed. A base MS Excel (Version: MS Excel 2017) was made which becomes the database for operational dashboard. The base MS Excel contains the planned versus actual status of each job. The planner has to update the actual status in the MS Excel for work order in planned versus actual sheet. In order to have a live connection between MS Excel and Power BI, the MS Excel is stored on one drive OR can be stored on SharePoint link. The user must have Windows 8.1 or above version along with Microsoft Power BI Desktop version installed in it. Minimum 2 GB of memory (RAM) with a monitor resolution of 1440 x 900 pixels and above is sufficient.

Each and every time the planner starts the planning activity before releasing to production, the planner should update the MS Excel with the actual status of previous ongoing orders and also update the job and machine schedules recommended by iteration summary sheet which recommends the number of shifts and machines to be planned in order to complete the workload under due date. There is extensive use of data analysis expression (DAX) functions and time intelligence functions while creating the measures in the power BI. The *figure 6* represents the flow chart of MS Excel - Power BI dashboard integration.

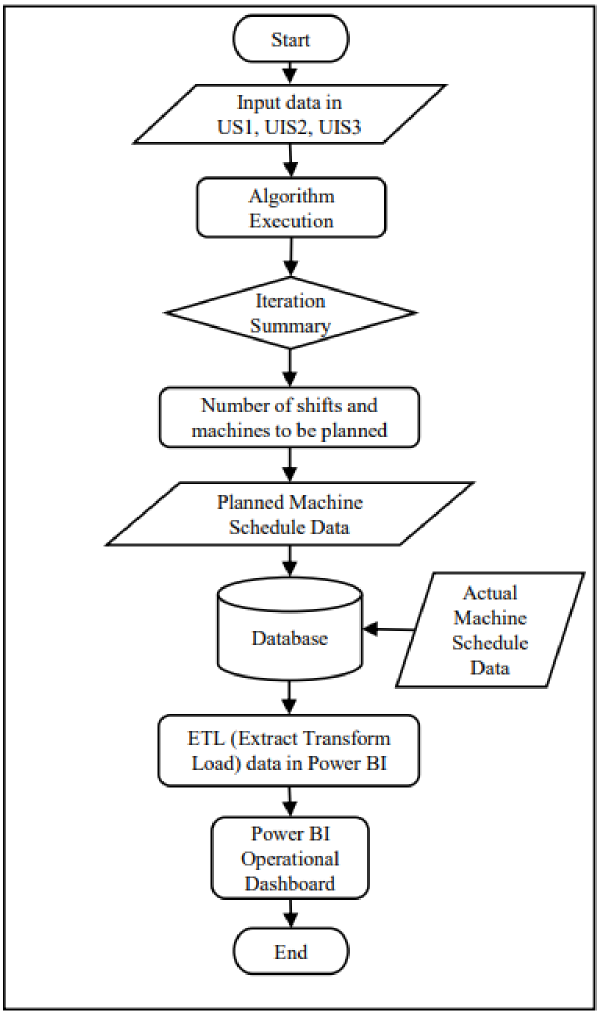

Fig. 6 MS Excel - Power BI Integration flow diagram

The planned versus actual sheet is the foundation of the dashboard which is imported in Power BI with the help of connection tabs. The data then undergoes various transformations in power query editor where the data type of each column is decided. It's important to give the data type before analysing the data. Wherever there is date and time involved such as planned start date, planned start time, planned end date, and planned end time, it's necessary to format cells and amend the data type to date and time format so that Power BI interprets it as date and time and not a whole number. In data modelling, various active relationships are built in between the planned dates and actual dates so as to analyses the gap in-between both. Finally the report view publishes the dashboard highlighting various key performance indicators (KPIs) of the parallel machine environment

Operational Dashboard

In order to analyze the performance of the shop floor, various KPIs were selected while developing the dashboard. The planner can draw number of insights from the operational dashboard while executing the planning activity which can help him for decision making. The *figure 7* represents the operational dashboard in the Power BI as observed on May 29, 2023 (Start Date of Week 13). The most important metric is order status which depicts the distribution of orders completed, orders pending and orders in progress. This metric can help the planner to visualize how much of the current orders are yet to start which in turn indicates the need of the resources to complete the existing workload. The due date performance indicates the number of orders which can be completed ON TIME by planning for given number of shifts and machines.

It also helps the planner to identify the orders which are likely to be overdue meaning failure for ON TIME delivery due to updates of breakdown timings and actual order completion entries through UIS. The planner can then evaluate based on his experience whether this delay is acceptable or not. The cumulative downtime in minutes highlights which machine faced the most unproductive time causing impact on the timelines of the jobs. The downtime includes breakdown, unplanned stoppages and non-operational time. In the above simulated scenario it is seen that machine no. 3 experiences highest breakdown. This means that planner can plan the preventive maintenance of the machine no 3. Thus the metric highlights the machine on the shop floor which needs to be undergo preventative maintenance. The cumulative OEE takes into account availability (A), performance (P) and quality (Q).

There is no need to run simulations by executing any external “Run” command. As soon as the planner enters the details in UIS 1, UIS 2, and UIS 3 (Refer Table 3) the iterations are getting executed by MS Excel formulation and the result of number of shifts and machines to be planned for given workload is displayed in Green Tab in iteration summary sheet (Refer Fig 4).

For the system proposed here in this paper, each time the planner enters inputs, there are 18 iterations executed with various shift and machine combinations. The best possible combination of shift and machine which satisfies the customer due date is highlighted in the result tab in the iteration summary sheet. The planner has to directly plan the shop floor based on the result displayed so as to fulfil the customer due date. The operational dashboard is the representation of KPIs those get displayed as a result of planning as per the results shown in the iteration summary.

In the simulated scenario presented in this paper, it is found that OEE of all machines is greater than 90 % indicating a good performance of the shop floor .The shift planning overview is the most important parameter indicating the nature of shift planning over weeks. In the simulated scenario presented in this paper, it is seen that the number of shifts planned has been increased from 1 to 3 up till week 4 and thereafter reduced to two shift planning. This drop from three shift planning to two shift planning is due to decrease in the workload forcing the planner to lower one shift. The machine planning overview indicates the nature of number of resources used to complete the given workload as one progress weekly. In the current simulated scenario, its seen that number of machines have been increased from 1 to 5 and then decreased to 2. This drop in number of machines planned from 5 to 2 is due to the decrease in the workload. Thus both the KPI indicate the nature of Shift and machine planning as planner progresses weekly.

The operational dashboard also projects the machine schedule, providing the details such as start date and time, end date and time and machine allocated for a particular job code. The operational dashboard indicates the performance of the shop floor and provides a bird’s eye view for planner to look way forward and plan the resources accordingly to complete the given workload under due date.

4. Results and Discussion

Table 7 shows results of 6 simulations that were executed for week 1 to week 6. The batches that arrived in week ‘n’ have their cycle times determined in week ‘n+1’ and the production starts in week ‘n+2’ which has to be completed latest by week ‘n+6’. The batches arrived in week 4 have their cycle times determined in week 5 and production starts in week 6 which gets completed by week 10.

The workload hours represents the total production hours that are required to complete the production of the work orders of that particular week. For orders of week 4 which start their production in week 6, the total production hours of this lot of orders that have arrived in week 4 is 1215.8 hours. This 1215.8 hours of load has been loaded over the 5 machines planned for 3 shifts so that production converts this jobs to finished goods before the due date.

Table 8 shows the details of downtime and OEE per week and cumulative till the start of week 13. *Table 9* shows the details of number of orders received per week, orders completed per week and due date performance obtained over the entire period of 12 weeks.

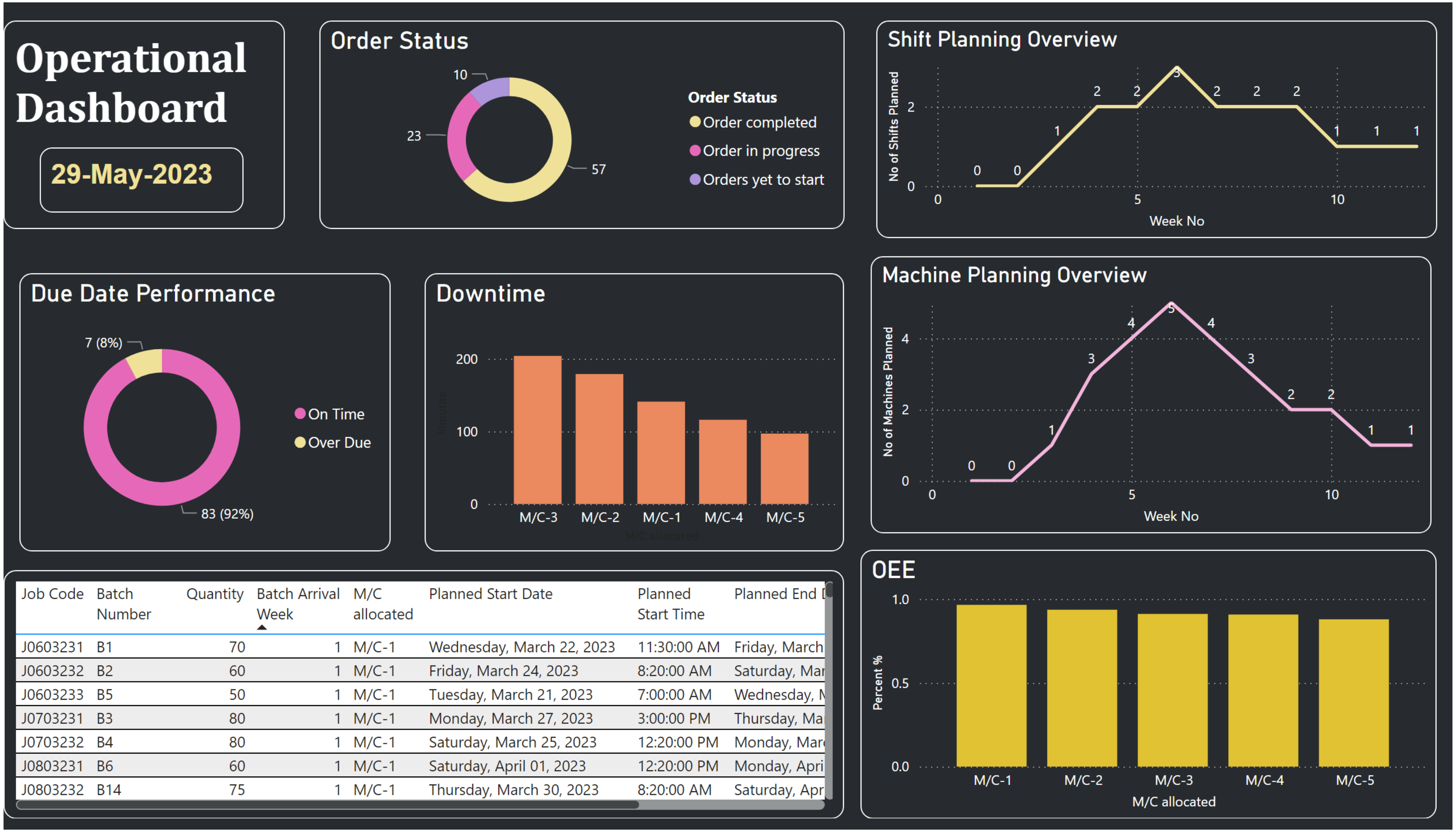

Fig. 7 Operational dashboard for parallel machine scheduling environment on May 29, 2023 (Start Date of Week 13)

Note: The dashboard can be displayed in three settings - adjust automatically, scroll automatically and fixed interval. Currently the dashboard is set on adjust automatically which adjusts the timeline frame of dashboard automatically and provides cumulative informatio

Table 7 Results of 6 simulations that were executed for week 1 to week 6

Batch arrival week no.	Cycle time determination week no.	Production start week no.	Customer due date week no.	Workload in hrs.	Number of shifts planned	Number of machine planned
1	2	3	7	227.2	1	1
2	3	4	8	975.0	2	3
3	4	5	9	804.2	2	4
4	5	6	10	1215.8	3	5
5	6	7	11	519.3	2	4
6	7	8	12	259.7	2	3

Table 8 Details of downtime and OEE recorded for week 1 to week 12

Batch arrival week no.	Cycle time determination week no.	Production start week no.	Downtime in minutes					OEE in %				
			M/C1	M/C2	M/C3	M/C4	M/C5	M/C1	M/C2	M/C3	M/C4	M/C5
1	2	3	-	-	-	-	-	-	-	-	-	-
2	3	4	-	-	-	-	-	-	-	-	-	-
3	4	5	18	-	-	-	-	96.46	-	-	-	-
4	5	6	15	30	60	-	-	98.78	93.55	90.11	-	-
5	6	7	15	24	30	30	-	97.78	91.64	91.55	91.55	
6	7	8	18	30	42	48	96	95.82	92.70	92.58	90.52	90.05
7	8	9	24	30	36	36	-	97.64	94.55	90.46	90.46	-
8	9	10	12	30	36	-	-	93.82	93.55	92.46	-	-
9	10	11	12	24	-	-	-	95.82	92.64	-	-	-
10	11	12	6	12	-	-	-	93.82	92.64	-	-	-
11	12	13	0	-	-	-	-	95.82	-	-	-	-
12	13	14	12	-	-	-	-	94.64	-	-	-	-
		Cumulative	132	180	204	114	96	96.04	93.03	91.43	90.84	90.05

Table 9 Details of orders received, orders completed and due date performance for week 1 to week 12

Batch arrival week no.	Orders Received	Orders Completed	No. of orders completed on time	No. of orders became overdue
1	4	-	4	-
2	13	-	11	2
3	11	1	9	2
4	15	2	12	3
5	8	4	8	-
6	6	12	6	-
7	5	10	In Process	-
8	7	9	In Process	-
9	6	10	In Process	-
10	5	4	In Process	-
11	5	3	Not yet started	-
12	5	2	Not yet started	-
Cumulative	90	57	50	7

The simulation starts with batch arrival week no. 1 where all the machines are available. There is workload of 227.2 hours which is sufficient to be completed by planning 1 shift on 1 machine. As we move to next week, the workload is increased 3 times of week no 1 which results in planning two additional machines on 2 shifts to complete the workload before the customer due date (week 8). Thus the planning that was 1 shift planned on 1 machine for week 1 work orders now has amended to 2 shifts planned on 3 machines to complete week 2 work orders along with week 1 work orders simultaneously. It is to be noted here that the work orders that have been booked on 1 machine for week 1 work orders is booked till week 7.Thus the work orders that have arrived in week 2 have been allocated on 2nd and 3rd machines running the plant simultaneously with both weeks work orders. It can be seen that the workload has been increasing from week 1 to week 4. The workload is highest in week 4 of 1215.8 hours. The production of week 4 work order starts in week 6 and the entire parallel machine scheduling is planned for 3 shifts on 5 machines. Due to high workload the entire day of 24 hours (3 shifts) has to be utilized by the planner to achieve the customer due date. The work orders that arrival in week 5 have almost half the workload hours of week 4 i.e. 219.3 hours which force the planner to reduce its scope of resources and plan 2 shifts on 4 machines to complete its production under week 11. There is further reduction of workload in week 6 work orders making plant run on 2 shifts planned on 3 machines. *Figure 8* shows the shift planning and machine planning. X-axis represents the week number and Y-axis represents the number of shifts and machines planned in that week. *Figure 8* is useful for the resource planning of the shop floor. Here resource planning refers to number of shifts (Manpower) and number of machines to be planned to complete production. Being an MSME, the workload hours is not constant. The resource planning of the shop floor depends upon the workload hours. By looking at shift planning and machine planning KPI, the planner gets to know that how the resource planning need to done for the plant for the planned period. For example, as seen in figure 8, from week 6 to week 7, the number of shifts have reduced from 3 to 2 and number of machines have reduced from 4 to 3, which indicates the planner to reduce one resource from the shop floor (one manpower and one machine). Thus the plant runs at optimal resources completing the workload hours and also satisfying the customer due date.

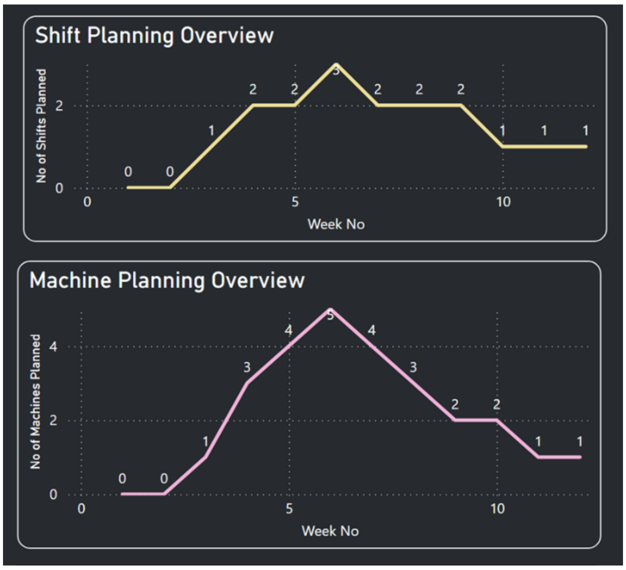

Fig. 8 Shift Planning and Machine Planning Overview

As can be seen from *table 7*, the production starts in week 3 (week 1 work orders) with the workload of 227.2 hours planning 1 shift on 1 machine and increasing in week 6 (week 4 work orders) there is a spike in both the graphs of shift and machine planning overview. After week 6 you can see a decreasing trend for week 7 and week 8. The operational dashboard is competent enough to display entire planning scenarios on weekly basis.

This case study considers MSME where there are limited IT resources. MS Excel being a user-friendly tool in any industry it is easy to integrate with the Power BI desktop version which is an open resource tool. The power BI has an import option which makes easy to import data from MS Excel and CSV files quite fast. However, if the data is too large (for example more than 30 weeks) this might result in loading issues of data in power BI and fear of file corruption. It is recommended to have excel data less than 30 weeks in order to experience a smooth working of MS Excel - Power BI integrated system to avoid data corruptions and data migration complexities.

Scalability and sustainability are critical factors for the long-term viability of any solution, particularly for MSMEs. Careful consideration has been given to these aspects throughout the development and implementation phases of this proposed system. Firstly, regarding scalability, the proposed solution is designed to accommodate the evolving needs and growth trajectories of MSMEs. The flexibility inherent in both MS Excel and Power BI allows for easy customization and adaptation to varying production scales and complexities. Several machines can be added further until the scheduling environment is for parallel machines. Moreover, the proposed system architecture is modular, enabling seamless integration of additional features and functionalities from the dashboard point of view as the business expands. Secondly, with regards to sustainability, there is need to consider following points: (i) train the MSME personnel to ensure the ongoing maintenance and support of the system, (ii) awareness about regular updates to address any software compatibility issues or security vulnerabilities, (iii) MSME personnel to obtain comprehensive training and prepare documentation to empower MSMEs to independently manage and optimize their production scheduling processes.

5. Conclusion

The 6 simulations were simulated on the PP system by the planner for shift and machine planning to meet the order completion due date. Among the various kinds of dashboards for various scenarios **[10]-[13]**, this is the first-ever dashboard preparation to provide visibility of number of machines and number of shifts planned for an MSME working with parallel machine environment. The MS Excel - Power BI integration has been successfully implemented to meet most of the objectives through dash boarding. This study offers a feasible and practical approach for MSMEs to enhance their resource planning visibility. It suggests the creation of a dashboard that integrates MS Excel - Power BI, providing a cost-effective solution. It is observed that the shift and machine planning depends upon the total production hours required to complete the work orders that have been arrived in that particular week. The more the production hours, more number of shifts have to be planned with machines. A proper combination of shift and machine can be selected based on the availability of the machines. Increasing shift or machine to the scheduling environment increase the total available hours to complete the production. The planner must keep in mind that the work orders cannot be planned on all the available machines, as doing so will result in completing the production too early resulting in longtime idleness for the plant which is not economical in the case of MSME. Also, as its MSME most of the jobs that have come to production are unique and once the setup and process has been standardized the entire production is produced in one go on the general purpose machines. The delays that have happened are traced by plan VS actual sheet with the help of actual inputs punched by planner which are reflected on weekly basis. The machine downtime KPI on operational dashboard reflected highlights of the machine which is responsible for delaying the job readiness. Also, these delays result in overdue of work orders which can be seen in due date performance KPI on operational dashboard. For current scenario as shown in *figure 5*, 8% work orders have been overdue and failed to achieve the customer due date due to these delays.

Despite fluctuating workload over six weeks, (i) 92% orders met the 45-day lead time, (ii) plant ran continuously for a month (100% achievement), and (iii) visibility for stakeholder was enhanced with efficient resource planning.

It can be concluded by looking at the operational dashboard and results presented in Table 7, that MS Excel - Power BI integrated PP system can be adapted by an MSME which has a parallel machine scheduling environment. It is cost-effective model where friendly tools like MS Excel and open resource tools - Power BI desktop is used for daily/weekly effective production planning, unlike the other APS software which require high investment and skilled IT expertise to run ERP software [28]-[30].

All the three cases [10], [11], [13] doesn't address the scheduling activity within production planning system via MS Excel and Power BI integration. The present paper uses the functionality of MS Excel by having complex formulation resulting in carrying out iterations and giving the best possible output of "number of shifts and number of machines to be planned" to achieve the customer due date and keep the plant running for one month. The dashboard developed using Power BI not only displays the KPI but also gives an overview of shift and machine planning which is useful for planners in resource planning of shop floor.

This case simulated a scenario for MSME with MTO production strategy. In the future, if we simulate for MTS production strategy, we'll skip determining work order arrival week and cycle time. Instead, the work order will go straight to production the day after it arrives. For MTS strategy the quantity would be determined by subtracting the stock in finished goods and work in progress (WIP) inventory from the total order quantity received from customer.

The present parallel machine scheduling scenario works on the FCFS rule and there is no scope for planner to change the sequence of the work orders based on priority. There is future scope on this segment where the work can be carried out to make the PP system more realistic. There are other sequencing rules such as shortest processing time (SPT), longest processing time (LPT), earliest due date (EDD) which may change the sequence of the work orders. There is a room to work on this where the PP system has to be compatible according to the rule followed by planner to plan the work orders on the machines. There is room for optimization where the concept of resource leveling and line balancing can be used to club the work orders in groups (Kilbridge and Wester Method, Largest Candidate Rule, Ranked Positional Weight method) and allocate the groups on the machines in such as a way that there is even distribution of workload hours and no machine is overloaded OR under loaded, thus increasing the productivity of the scheduling scenario. In the present scenario the batch splitting possibility is not considered which also give optimization due to significant reduction in may make span time thus improving the dynamisms of the PP system. Also, there is future scope for the present PP system to be analyzed with economic considerations as per the controlling module of standard ERP software. The overtime scenario can also be analyzed from economic point of view.

The academic contribution of this study is multifold. Firstly, it addresses a real-world problem faced by MSMEs in the domain of production scheduling. By integrating MS Excel and Power BI, this study offers a solution that is not only accessible but also affordable for MSMEs, which may lack the resources for more complex systems. Secondly, it demonstrated the importance of digitalization and data visibility of KPIs through dashboards leading to performance improvement of MSMEs. Thirdly, this study also contributes to the field of operations management. Designing a production scheduling system and understanding its effect on the operations can be understood effectively through a simple integration of MS Excel and Power BI. This demonstrates to understand that how smaller enterprises can optimize their production processes with limited resources. Lastly, thought provoking inputs are triggered with integration of MS Excel and Power BI that how this methodology could be applied to other areas of research or industry sectors beyond production scheduling. These aspects can be included and explained in the laboratory courses related to production scheduling or operations management domain. Thus this study contributes as an educational resource for students and professionals interested in operations management and technology integration.

Conflicts of Interest

The authors have no conflicts of interest to declare.

Authors' Contribution Statement

PSP: Conceptualization, data acquisition, data collection, data curation, data analysis, writing original draft, and interpretation of results. **SSP:** Data analysis, design, data representation, interpretation of results, writing original draft, and reading proof. **SMP:** Conceptualization, study conception, writing original draft, interpretation of results, supervision, review, reading proof, and the revision of the whole article. **MRD:** Data acquisition, data collection, data curation, data representation and reading proof.

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