Flowshop Production Scheduling Using the Theory of Constraints Approach: A Case Study in the Leather Glove Industry

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Abstract. The smooth flow of production in industries characterized by repetitive make-to-order flowshops is often constrained by workstations with long processing times and limited capacity. This condition frequently results in delays in completing all orders. The goal of this research is to create a production schedule that aligns with the company's actual capacity using the Theory of Constraints approach and the Drum-Buffer-Rope logic system with the Zijm algorithm. Based on the research findings, it was determined that scheduling using this method effectively addresses constraints that impede production flow by reducing bottlenecks. As a result, the average manufacturing lead time was reduced by approximately 31.25% compared to the company's previous manufacturing lead time.

Keywords: production scheduling, theory of constraints, drum-buffer-rope, zijm algorithm

1 Introduction

The rapid development of the industrial world demands companies to compete with their competitors by establishing good credibility in the eyes of consumers [1]. One way to do this is by delivering orders on time and meeting the desired specifications. This is crucial, especially in make-to-order industries where companies face uncertain order quantities, arrival times, and due dates. Therefore, effective production control is required to optimize resource utilization and fulfill customer orders as desired. Proper production scheduling is highly relevant for addressing these challenges. Production scheduling is defined as a set of instructions or indications of what needs to be done, with whom, and with what equipment to complete a job at a specific time [2]. Scheduling is the comprehensive ordering of product manufacturing carried out by several machines [3]. According to Baker [4], the objectives of scheduling are to 1) increase machine productivity, 2) reduce work-in-process inventory, 3) minimize delays, and 4) minimize production costs.

PT ASA is a company that manufactures golf gloves made from organic and synthetic leather. These golf gloves are a commodity exported to several countries worldwide. The production system used is a make-to-order repetitive one, with product demand variations that are not significantly different and repeated orders in a short timeframe. Historically, the company has prioritized early incoming orders. In general, PT ASA has four production departments: cutting, stitching, finishing, and packaging, with a flow shop process flow pattern.

Flowshop scheduling is a scheduling model where all the jobs to be processed flow in the same direction or the jobs have the same sequence of operations. Typically, in a flowshop

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production system, there are several machines (m), a certain number of jobs to be processed (n), and the processing time per unit of job i on machine j. Flow shop scheduling is often solved by developing permutations of the job sequence to be ordered. Jobs are independently available simultaneously at time zero, and the machine sequence for all jobs is the same. Each job has processing times on each machine. Flow shop scheduling is characterized by one-directional and specific workflow [5].

Based on observations, it is evident that not all production flows smoothly. Currently, there is a significant accumulation of work-in-process (WIP) goods, especially at the sewing workstation, which has the longest processing time. The production scheduling in the company is still based on daily targets and not on the actual capacity at each workstation. However, golf glove manufacturing requires a relatively long time. This results in long WIP queues, thereby extending the time to complete all orders. At certain times, the company still often works overtime, especially for sewing operators, to meet production targets. Nevertheless, there are still instances where some orders are completed late. When there is an indication of potential delays, the company usually negotiates with customers for an extension of the completion time. Of course, this can adversely affect the company's credibility in the eyes of its customers. The company realizes that maintaining customer trust is crucial, given the presence of many competitors in a similar line of business. However, there has been no effective action taken from the company to address these issues.

If these problems are left unattended, the company will incur more losses. These losses result from delayed order completions, leading to the implementation of overtime work and, of course, incurring overtime costs. Additionally, the customers' trust in the company is at risk of declining. Workstations that act as constraints can be the cause of bottlenecks, so solutions need to be found for the problem. Scheduling based on the heaviest workload can result in a more effective production scheduling method in line with the company's actual capacity.

Therefore, the goal of this research is to plan an appropriate production schedule that aligns with the company's actual capacity to optimize the constrained workstations for smooth production. The hope is that production targets are met, the company can complete orders on time, and, as a result, the company's performance in the eyes of consumers can be improved. The approach used to address the issues in this research is the Theory of Constraints (TOC) approach with the Drum-Buffer-Rope (DBR) logic system. The TOC approach is a concept of optimized production technology that emphasizes the optimization of constrained workstations [6]. Meanwhile, DBR is a production control technique to implement the steps in TOC. To identify the parameters required in scheduling with DBR logic, the Zijm algorithm is used. The fundamental logic of the Zijm algorithm is to identify the bottleneck workstation by detecting the machine with the longest processing time, the largest average workload, and the largest job waiting time expectation.

2 Research Method

2.1 Theory of Constrain

Optimized Production Technology (OPT) is a technique for optimizing production scheduling with the aim of maximizing throughput while minimizing inventory and operational costs [6]. The OPT concept emphasizes the optimization of constrained workstations, and this

approach is also known as the Theory of Constraints (TOC). Improving throughput using the TOC approach is known through the five TOC steps for improving the system [7], which are:
1. Identify the constraints in the system.
2. Exploit the constraints.
3. Subordinate all other parts of the manufacturing system.
4. Elevate the constraint's capabilities to solve problems.
5. If the old constraint is solved but a new constraint appears, return to step 1.

The system improvement steps aimed at by TOC emphasize and concentrate the method on the constraint workstation, with the constraint workstation following the results obtained from the previous constraint workstation. This focus simplifies the scheduling process as it only requires finding a schedule that aligns with the constraint without considering the entire schedule of other work elements.

A constraint is anything that hinders a system from achieving higher outcomes that are the goals of the system [7]. There are two types of constraints [8], bottleneck and capacity constraint resource. A bottleneck occurs when its capacity is the same as or smaller than the demand. In contrast, a constraint resource is a source that causes a bottleneck because its usage or utilization is inefficient.

Although TOC focuses on the constraint stations, other non-constraint stations will undoubtedly affect the scheduling done at the constraint station. Scheduling at the constraint station will require a very small level of deviation between the plan and the actual, and in general, constraint stations are set to operate at 100% capacity. Consequently, a buffer is required to absorb all potential fluctuations at non-constraint stations, ensuring that the schedule at the constraint station remains undisturbed. Therefore, TOC proposes the use of a buffer for the constraint station, known as a constraint buffer.

2.2 Zijm Algorithm

The basic logic of the Zijm algorithm is to identify the bottleneck workstation by detecting the machine with the longest processing time, the largest average workload, and the greatest expected waiting time for each job. Once the machine experiencing the bottleneck is known, the Zijm algorithm generates a time buffer, which is then used to manage fluctuations at the preceding workstations. The mathematical model of the Zijm algorithm [9] is as follows:

1. Calculate the arrival rate for each job

$$D^{(h)} = \frac{1}{MLT} = \frac{1}{(d^{(h)} - r^{(h)}).m} \tag{1}$$

$$\lambda_{jk}^{(h)} = \frac{D^{(h)}}{Q^{(h)}} \; x \; \delta_{jk}^{(h)} \tag{2}$$

2. Calculate the processing time for each job

$$P_{jk}^{(h)} = Z_{jk}^{(h)} + \left(Q_{jk}^{(h)} \; x \; a_{jk}^{(h)}\right) \tag{3}$$

3. Calculate the average workstation load for each workstation

$$\rho_j = \sum_{h.k} \lambda_{jk}^{(h)} \; x \; P_{jk}^{(h)} \tag{4}$$

4. Calculate the expected average waiting time for each job at each workstation

$$E(j) = \frac{\sum_{h.k} \lambda_{jk}^{(h)} \; x \; \left(P_{jk}^{(h)}\right)^2}{2(1 - \rho_j)} \tag{5}$$

5. Calculate the expected average production lead time for job h at operation k in workstation j

$$E\left(T_{jk}^{(h)}\right) = E(j) + P_{jk}^{(h)} \tag{6}$$

6. Calculate the expected average lead time for job h

$$E(T^{(h)}) = \sum_{j.k} \delta_{jk}^{(h)}\ x\ E(T_{jk}^{(h)}) \tag{7}$$

$$ETC^{(h)} = r^{(h)} + \sum_{h=1}^{m}(t_h - w_h) \tag{8}$$

$$LTC^{(h)} = d^{(h)} - \sum_{h=1}^{m}(t_h + w_h) + t_b \tag{9}$$

2.3 Drum Buffer Rope

Drum-Buffer-Rope (DBR) is a production control technique used to implement the steps in TOC: exploitation, subordination, and elevation. When a system has a bottleneck station, this bottleneck station naturally becomes the system's overall control point. The production rate of the bottleneck station determines the overall system's production rate [8]. The DBR logic system focuses on limited scheduling mechanisms that balance the flow or path of a system. DBR controls the flow of materials to meet market demand with inventory and operating expenses according to the plan.

According to Fogarty [7], the drum is the central control point and should be placed where the system contains a bottleneck because the bottleneck is the best place to control production flow. The drum represents the master production schedule (MPS), determining the average production of the entire system. The drum is used to ensure that operations do not overproduce and add to the existing WIP. Places to put the drum include the bottleneck, capacity constraint resource, as well as divergence and convergence points.

On the other hand, the buffer is used to protect the bottleneck from fluctuations in previous workstations. It also ensures that the production rate is not disrupted by any disturbances. In a production system, there are two types of buffers:

1. Time buffer, which is a time used as a buffer to protect the production rate (throughput) of the system from the disturbances that typically occur in the production system.
2. Stock buffer, which is the finished product used as a buffer to enhance the production system's responsiveness to demand.

The rope acts as a link for the production rate between constraint and non-constraint stations. The presence of the rope reduces the inventory at each workstation and maintains it at a certain level. In other words, the rope serves as a communication tool between the bottleneck and the materials delivery section. The delivered raw materials are only as much as what the bottleneck needs.

The notations used are as follows:

h : job h (h = 1, 2, 3, …, n)
j : machine j (j = 1, 2, 3, …, n)
${\lambda_{jk}}^{(h)}$: arrival rate of job h at station j for operation k
$D^{(h)}$: demand rate of job h
$Q^{(h)}$: production lot size

$\delta_{jk}{}^{(h)}$: 1; if operation k of job h is performed at station j
0; if any of the above conditions are not met
$a_{jk}{}^{(h)}$: processing time per unit for operation k of job h performed at station j
$\tau_{jk}{}^{(h)}$: set-up time
$P_{jk}{}^{(h)}$: operation k of job h processed at station j
ρ_j : workload at station j
$E_j{}^{(h)}$: waiting time in the queue at station j
$L_{jk}{}^{(h)}$: lot number of job h in the queue and in progress at station j for operation k
$t_d{}^{(h)}$: job arrival time on the shop floor after being accepted
$t_s{}^{(h)}$: current time
T_j : station completion time working on job h
$B_{jk}{}^{(h)}$: load of station j to process operation k of job h
B_j : total load of station j to process all job h received
$I^{(h)}$: operation of job h performed on the constraint station
c : the constraint station
$P_{cl}{}^{(h)}$: operation time for operation 1 of job h at the constraint station
$f_{jk}{}^{(h)}$: completion time for operation k of job h at station j
$S_{jk}{}^{(h)}$: start time for operation k of job h at station j
$dd^{\ (hh)}$: dispatch time of job h
$P_t(h)$: total processing time of job h

The steps of Drum-Buffer-Rope (DBR) as outlined [7] are as follows:

1) Initialization Phase
   a) Determine when the job can start being processed at station j.
      If $t_{(d)}$ = 0 (shop is empty), proceed to step two for determining the constraint station. Set *Tj* = 0, if job arrive with stations occupied (job are already in progress). Remove operations from jobs with
      Hapus operasi dari job yang $t_{start} < t_s$ that have not been completed at station j.
   b) Set $t_d = t_s = 0$
      Determine the station readiness time for processing job h. T_j = completion time with dengan $t_{start} = t_d$ of operations not yet completed at station j .
   c) Calculate the overall planning horizon for all jobs received at time t using the estimated process times and planning horizon procedure.
2) Constraint station determination phase
   a) Choose one of job h
   b) Calculate the material requirements for each level based on customer demand. In this study, material requirements are not calculated based on the quantity of jobs.
   c) Calculate the load of each workstation j to process operation k of job h.

$$B_{jk}{}^{(h)} = D^{(h)}\ x\ P_{jk}{}^{(h)}\ x\ \delta_{jk}{}^{(h)} \tag{10}$$

   d) Select another job and return to step b until all jobs have their load calculated.
   e) Calculate the total production load to be borne by each station j to process all operations of job h.

$$B_b = \sum_{jk} P_{jk}(h) \tag{11}$$

f) Identify the station j with the highest total production load as the constraint station.

3) Constraint station setup phase
   a) Calculate the size of the buffer to be placed in front of the constraint station using the Zijm waiting procedure.
   b) Determine the sequence of processing operation 1 for all job h operations at this constraint station with the earliest ready time or the time the product is worked on first at the constraint station. The sequence of products and/or job components worked on two or more times at the constraint station.
   c) Determine the start time for processing operation 1 of the product and/or job h at the constraint station.

4) Detailed production scheduling determination phase
   a) Calculate the release time to the shop floor until the lowest level of job h. Old jobs do not need to have their descent times recalculated because they are already on the shop floor and only await completion at station j.

$$r_j{}^{(h)} = S_{el}{}^{(h)} = \left[\text{Buffer}_j + \sum_{k=1}^{i-1} P_{jk}^{(h)}\right] \tag{12}$$

   b) Check the ready time, T_j for each station j.
      - If $T_j < S_{jk}{}^{(h)}$ for the first operation at the station, no adjustment is necessary
      - If $T_j > S_{jk}{}^{(h)}$ for the first operation at the station, make an adjustment
      - If $T_j = S_{jk}{}^{(h)}$, add the difference between T_j and $S_{jk}{}^{(h)}$ for the first operation at the station to adjust the time $S_{jk}{}^{(h)}$ for the next operation at the station.
   c) Determine the dispatch time for each job h

$$dd(h) = f_{el}{}^{(h)} + \sum_{i=1}^{k} P_{ji}{}^{(h)} \tag{13}$$

3 Result and Discussion

The data used in this study includes order data, processing time data for each workstation, machine type data, the number of operators per workstation, and production sequence in initial conditionsas, seen in Table 1, Table 2, and Table 3.

Table 1. Order Data

No	Customer	Model	Quantity (Pieces)	Order Entry	Ready to Production	Target Completion	*Due Date*
1	Holborn	Suede	230	18-May	3-June	19- June	26- June
2	Bridgestone Jpn	Tour Premium	820	21-May	3- June	24- June	31- June
3	Galaxy	Call El Paseo	360	28-May	3- June	18- June	25- June
4	Galaxy	Smooth	360	28-May	3- June	20- June	27- June

5	Lezax Osaka	Suede	1200	20-May	3- June	7- July	14- July
6	Lezax Osaka	Suede	2000	21-May	3- June	9- July	16- July
7	Galaxy	E-Glove	3600	28-May	3- June	11- July	18- July
8	Lezax Osaka	Suede	1200	27-May	3- June	21- July	25- July
9	Lezax Osaka	Suede	1400	25-May	3- June	21- July	28- July
10	Galaxy	Tour Premium	5760	28-May	3- June	1-August	8- August
11	Lezax Osaka	Suede	800	28-May	3- June	2- August	9- August
12	Bridgestone Jpn	Tour Authentic	4000	29-May	3- June	5- August	12- August
13	Callaway Jpn	Call Star	576	29-May	3- June	6- August	13- August
14	Oakley Jpn	Skull Golf	2827	28-May	3- June	10- August	16- August
15	Oakley Jpn	Skull Golf	3419	29-May	3- June	12- August	19- August
16	Oakley Jpn	Skull Golf	5380	30-May	3- June	15- August	22- August
17	Bridgestone Usa	Tour Premium	2888	30-May	3- June	16- August	23- August

Table 2. Process time each workstation

Department	Work Station	Activity	Number of Operators	Process Time (hours)	Production Capability
Cutting	SK 1	Aradachi	10	34.2	58979
	SK 2	Selection I	2	27.4	4205
	SK 3	Press pattern	6	23.8	36367
	SK 4	Punching	2	31.5	13695
	SK 5	Selection II	1	11.7	4937
	SK 6	Cutting of machi	4	29.4	3923
	SK 7	Matching	4	29.1	3964
Sewing	SK 8	Sewing preparation	2	22.5	3832
	SK 9	Seaming of acces	9	32.6	7066
	SK 10	Sew accessories	6	36.5	3940
	SK 11	Attach velcro	3	32.3	3563
	SK 12	Attach size & logo	3	54.8	2627
	SK 13	Attach rubber	3	39.2	2940
	SK 14	Attach thumb	3	53.0	2719
	SK 15	Thumb closure	3	11.2	5165
	SK 16	Cutting of machi	3	54.2	2658
	SK 17	Cutting of omo	3	48.2	2392
	SK 18	Cara H	6	40.2	4300
	SK 19	Lipat omo	5	58.8	4407
	SK 20	Attach button	3	45.2	3185

	SK 21	Sew ribbon	3	27.1	4248
	SK 22	Kumis-kumis	6	25.2	6870
Finishing	SK 24	Ironing	6	48.2	17943
Packing	SK 25	Inspection	1	1.0	28800
	SK 26	Polybag	2	20.0	5760
	SK 27	Inner Box	2	18.1	9552
	SK 28	Big Box	1	2.0	14400

Table 3. Production sequence in initial conditions

No	Production Code	Customer	Model	Total Processing Time (hours)
1	AGS 1	Holborn	Suede	11.51
2	AGS 2	Bridgestone Jpn	Tour Premium	17.09
3	AGS 3	Galaxy	Call El Paseo	17.49
4	AGS 4	Galaxy	Smooth	28.29
5	AGS 5	Lezax Osaka	Suede	38.63
6	AGS 6	Lezax Osaka	Suede	40.63
7	AGS 7	Galaxy	E-Glove	57.66
8	AGS 8	Lezax Osaka	Suede	57.66
9	AGS 9	Lezax Osaka	Suede	67.18
10	AGS 10	Galaxy	Tour Premium	95.73
11	AGS 11	Lezax Osaka	Suede	127.14
12	AGS 12	Bridgestone Jpn	Tour Authentic	141.66
13	AGS 13	Callaway Jpn	Call Star	153.65
14	AGS 14	Oakley Jpn	Skull Golf	174.66
15	AGS 15	Oakley Jpn	Skull Golf	188.76
16	AGS 16	Oakley Jpn	Skull Golf	241.45
17	AGS 17	Bridgestone Usa	Tour Premium	156.34

The problem-solving stages in this research are divided into three phases: the identification of the constraint station using the Zijm algorithm, the determination of the time buffer at the constraint station, and the production scheduling using the Theory of Constraints approach with the Shortest Processing Time (SPT) priority rule.

Table 4. Proposed Production Schedule

No	Job Sequence	Start Time (hour)	Finish Time (hour)	Proposed Lead Time (hour)	Company Lead Time (hour)	Scheduling Status
1	AGS1	0.00	11.51	11.51	104	Feasible
2	AGS4	0.03	17.53	17.50	120	Feasible
3	AGS3	0.49	18.63	18.14	104	Feasible
4	AGS13	1.19	30.11	28.92	168	Feasible
5	AGS11	1.89	41.42	39.53	192	Feasible
6	AGS2	2.89	45.02	42.13	232	Feasible
7	AGS5	4.50	63.61	59.10	224	Feasible
8	AGS8	6.10	66.02	59.92	264	Feasible

9	AGS9	8.52	77.93	69.41	264	Feasible
10	AGS6	10.93	109.22	98.29	328	Feasible
11	AGS14	13.75	144.54	130.79	336	Feasible
12	AGS17	17.78	164.76	146.98	344	Feasible
13	AGS15	23.47	182.28	158.80	352	Feasible
14	AGS7	29.09	210.13	181.04	376	Feasible
15	AGS12	35.97	231.68	195.71	384	Feasible
16	AGS16	43.47	292.53	249.06	400	Feasible
17	AGS10	51.81	343.87	292.06	408	Feasible

Based on the Zijm algorithm, the workstation identified as the constraint is SK 17 because it has the highest total production load. To balance the overall process, a buffer is provided in front of SK 17, and SK 17 will simultaneously control the production pace. The size of the time buffer given at the constraint station is the total waiting time at the constraint station, which is 0.56 hours.

The sequence of work at the constraint station in the initial condition can be seen in Table 3. Meanwhile, the proposed scheduling using the SPT priority rule with the Drum-Buffer-Rope approach can be seen in Table 4. The scheduling will be considered feasible if the proposed lead time is shorter than the lead time given by the company for each job. The results of the proposed scheduling show a shorter manufacturing lead time than the actual lead time.

4 Conclusion

Production scheduling using the Theory of Constraints can provide the release time for each job to the production floor based on actual conditions. In the case mentioned, the constrained station is SK 17 because it has the longest total waiting time. The allowed buffer for each order at SK 17 is 0.56 hours, so each job to be operated at SK 17 will have a lead time that results from adding the total waiting time per work station to the job's processing time. Some products need to start production at a particular station before they are ready, but this can actually streamline the production process because these products enter the station just as the previous product is finished, avoiding any further delays in the production flow. The proposed scheduling can result in a shorter manufacturing lead time, averaging around 31.25% less than the company's manufacturing lead time.

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References

[1] S. Nasır, "Marketing Strategies in Competitive Markets and Challenging Times," in Customer Relationship Management Strategies in the Digital Era, IGI Global, 2015, pp. 1-24.
[2] R.G. Schroeder, Operations Management: Contemporary Concepts and Cases, International Edition. Mc Graw-Hill Companies, Inc., Boston, 2000.
[3] R.W. Conway, W. L. Maxwell, and L. W. Miller, Theory of Scheduling. Addison-Wesley, Reading, MA, 1967.
[4] K.R. Bakker and D. Trietsch, Principles of sequencing and scheduling. John Wiley and Sons, New York, New Jersey, 2009.
[5] K. Baker, Introduction to Sequencing and Scheduling. John Wiley and Sons, Inc., 1987.
[6] M.M. Umble and M.L. Srikanth, Synchronous Manufacturing. South-Western Publishing, Dallas, Texas, 1996.
[7] D. W. Fogarty, J.H. Blackstone, and T.R. Hoffmann, Production and Inventory Management, 2nd Edition. Southwestern Publishing, Cincinnati, 1991.
[8] D. Sipper and R.L. Buffin, Production Planning, Control, and Integration. McGraw Hill, New York, 1997.
[9] W.H.M. Zijm and R. Buitenhek, "Capacity planning and lead time management," International Journal of Economic, vol. 46-47, pp. 165-179, 1996.