OR 6205
DETERMINISTIC OPERATIONS RESEARCH

TITLE: PRODUCTION SCHEDULING AT FALCON DIE CASTING: A COMPREHENSIVE EXAMPLE ON THE APPLICATION OF LINEAR PROGRAMMING AND ITS EXTENSIONS

FINAL REPORT

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Project Brief

PROJECT NAME: PRODUCTION SCHEDULING AT FALCON DIE

ABSTRACT

This Project proposes a production schedule for five parts, five machines for 12 weeks utilizing both trial-and-error method (for question 1) and linear programming method (for the rest of the questions). to optimize resource utilization and minimize costs. A linear model is developed to minimize overtime while meeting demand, considering machine capacity, maintenance schedules, machine setup time and no inventory carryover while reducing the costs both in terms of labour and production.

This project has proposed two approaches: a trial-and-error method, which iteratively tests different schedules until a feasible solution emerges, and a linear programming model that mathematically calculates the best schedule minimizing overtime while fulfilling demand.

This project refines a production scheduling model to minimize overtime costs for both production and support staff. It incorporates the initial setup of machines, schedules production for weeks at a time, and allows finished goods inventory to be carried between weeks. The model identifies potential shortfalls and suggests machine utilization optimizations. It also shows FDC's commitment to being responsive to customer needs and their long-term policy of not maintaining finished goods inventory may be preventing them from taking full advantage of the new maintenance method. Relaxing these policies could lead to additional savings.

INTRODUCTION

The problem is for a production scheduling problem for five parts in five machines. The objective is to minimize the total machine hours of overtime needed to meet weekly customer demand, subject to various constraints, including machine capacity, production time per part, weekend maintenance schedule, yield rate and no inventory carryover.

The traditional approach of assigning overtime only to the most efficient machines can lead to uneven overtime distribution and higher overall costs due to required support personnel, even with lower total overtime pay.

The project proposes a week-on-week scheduling model that considers the initial setup of machines and allows finished goods inventory to be moved out and not be stored. This model can help to reduce overtime costs, improve machine utilization, and increase responsiveness to changing customer needs.

In simpler terms, the project shows a problem where a company needs to make a production schedule for five parts in a way that minimizes the need for overtime while meeting customer demand.
The traditional way of doing this is to assign overtime to the most efficient machines, but this can lead to problems like uneven overtime distribution and higher overall costs.

The paper proposes a new way to schedule production that takes into account the initial setup of machines and allows for no rollover of stock inventory. This new method can help to reduce costs, improve efficiency, and make the company more responsive to customer needs.

Falcon Die Casting's Production Problem:

Innovation and Contract:

Falcon Die Casting, a manufacturing company based in Ohio, has developed an innovative approach to tool manufacturing, securing a patent for their invention. This innovation impressed an automotive client, resulting in a long-term contract for Falcon to produce five specific parts over 12 weeks using their specially designed die-casting machines.

Client Requirements and Flexibility:

The client provided a 12-week demand schedule for the parts (Table 1). However, only the first week's demand is definitive. The remaining 11 weeks' requirements are subject to change based on the automotive company's current and previous week sales figures, introducing a dynamic element to production planning.

Production Capabilities and Considerations:

Falcon's five die-casting machines possess the versatility to produce multiple parts (Table 2). However, their individual yield rates vary depending on the specific part being produced (Table 4). The table 2 also gives data on how many parts can a machine produce at its maximum capacity. It necessitates strategic allocation of production tasks to maximize efficiency and meet demand with the highest yield machines.

Time Management and Labor Costs:

Production runs three shifts daily, eight hours each, totalling 120 regular weekly hours. An additional 48 hours are available for weekend work, but Falcon seeks to minimize weekend production to reduce overtime labour costs. Each machine requires setup time specific to the part it produces (Table 3). This factor adds another layer of complexity to scheduling, requiring careful planning to minimize downtime and optimize production flow.

Inventory Policy and Challenge:

Falcon adheres to a strict policy of not maintaining finished goods inventory due to associated costs. This presents a challenge: they must meet the client's fluctuating demand without carrying stock, requiring precise planning and flexible production adjustments while simultaneously minimizing costs.

Overall Goal and Balancing Act:

Falcon's primary objective is to develop a production schedule that satisfies the client's evolving demand within the stipulated timeframe and budget while adhering to their internal policies and limitations. This schedule needs to maximize production efficiency, minimize setup time, and utilize weekend work hours only when absolutely necessary.

1. Using a trial-and-error approach, propose a production schedule for meeting the first week's demand for the five parts.

Answer:

The Table1 given in the case study, it depicts the 12 week demand to produce the 5 different parts.

Projected Demand					
Week	Part 1	Part 2	Part 3	Part 4	Part 5
1	3500	3000	4000	4000	2800
2	3000	2800	4000	4300	2800
3	3000	2000	4000	3500	3000
4	3000	3000	4000	3800	2800
5	3000	3000	4000	4000	2800
6	3500	2500	4000	3800	2500
7	3500	2500	3800	4000	2500
8	3300	3400	3700	4200	2500
9	3300	3400	0	4500	3000
10	3200	3000	0	4500	3000
11	4500	4000	5000	5000	3800
12	3000	2800	4000	4300	2800

The Table2 is also given in the case study which gives the Production rate i.e. number of units that can be produced per hour on each machine corresponding to the multiple parts that every machine can produce

Production Rate (units/hour)					
	Part 1	Part 2	Part 3	Part 4	Part 5
Machine 1	40	0	0	60	0
Machine 2	35	25	0	0	0
Machine 3	0	30	0	0	45
Machine 4	0	35	50	0	0
Machine 5	0	0	0	60	50
Yield	0.6	0.55	0.75	0.65	0.6

The Table3 gives the Part setup time required for each machine corresponding to the 5 different machines.

Part Setup time (hours)	Part 1	Part 2	Part 3	Part 4	Part 5
Machine 1	8	0	0	8	0
Machine 2	10	8	0	0	0
Machine 3	0	10	0	0	24
Machine 4	0	8	12	0	0
Machine 5	0	0	0	8	20

The table 4 , the Production yield has been calculated by multiplying the yield and production rate from table 2

Production Yield Rate (units/hour)	Part 1	Part 2	Part 3	Part 4	Part 5
Machine 1	24	0	0	39	0
Machine 2	21	13.75	0	0	0
Machine 3	0	16.5	0	0	27
Machine 4	0	19.25	37.5	0	0
Machine 5	0	0	0	39	30

Part 3 can only be produced by machine three, hence it has to work full time in order to meet the demands for week 1. This is the bottle neck issue in the entire production scheduling. Taking this as our starting point, we came up with the required production hours, by trial and error method, that produces the required demands.

Here, we also have made sure none of the machines work for more than 168 hours in a week and taken into consideration the set up time required for each machine. All machines need to work overtime in order to meet the demand but the ovetime varies for each machine.

Production hours	Part 1	Part 2	Part 3	Part 4	Part 5	Total	120– machine setup time	120–mac setup + 48	Overtime out of 48
Machine 1	82	0	0	57	0	139	104	152	35
Machine 2	73	72	0	0	0	145	102	150	43
Machine 3	0	76	0	0	31	107	86	134	27
Machine 4	0	40	108	0	0	148	100	148	48
Machine 5	0	0	0	46	66	112	92	140	28

Machine 1 needs to work 120+35 hours

Machine 2 needs to work 120+43 hours

Machine 3 needs to work 120+21 hours

Machine 4 needs to work 120+48 hours

Machine 5 needs to work 120+28 hours

Output for week 1					
	Part1	Part 2	Part 3	Part 4	Part 5
Machine1	1968	0	0	2223	0
Machine2	1533	990	0	0	0
Machine3	0	1254	0	0	837
Machine4	0	770	4050	0	0
Machine5	0	0	0	1794	1980
Total	3501	3014	4050	4017	2817
Actual week 1 demand	3500	3000	4000	4000	2800

Output was obtained by simply multiplying the number of hours each machine worked to produce each part with their respective yield rates and the same parts produced by different machines were summed to find the total output for the week. We have obtained the most optimal solution through trial and error however we believe that this method is not feasible and thus we need to apply other optimization techniques in order obtain the most optimal solution

The Final results are also present in the same repo under this link:
https://github.com/sudeepparida3117/FalconDieCasting/blob/main/FinalResults.xlsx

2. Develop a linear programming model to determine the optimum production schedule that minimizes the total machine hours of overtime needed to meet the weekly customer demand. Assume that the weekend preventive maintenance effectively resets the machines so that new setups are required to start production each week. Note that in this scenario any remaining production time that is insufficient to setup for a new part, is simply lost. This is a consequence of the maintenance process and the company policy of not carrying

any inventory between weeks.

$$\text{Min}: \quad y_1 + y_2 + y_3 + y_4 + y_5 + y_6 + y_7 + y_8 + y_9 + y_{10}$$

__Demand constraints:__

$$x_1 + x_2 \geq 3500$$
$$x_3 + x_4 + x_5 \geq 3000$$
$$x_6 \geq 4000$$
$$x_7 + x_8 \geq 4000 \qquad\qquad z = 0 \text{ or } 1$$
$$x_9 + x_{10} \geq 2800$$

$$\frac{x_1}{40 \times 0.6} + 2_1 \times 8 + \frac{x_2}{60 \times 0.65} + 2_7 \times 8 \leq 120 + y_1 + y_7$$

$$\frac{x_2}{35 \times 0.6} + \frac{x_3}{25 \times 0.55} + 2_2 \times 10 + 2_3 \times 8 \leq 120 + y_2 + y_3$$

$$\frac{x_4}{30 \times 0.55} + \frac{x_9}{45 \times 0.6} + 2_4 \times 10 + 2_9 \times 24 \leq 120 + y_4 + y_9$$

$$\frac{x_5}{35 \times 0.55} + \frac{x_6}{50 \times 0.75} + 2_5 \times 8 + 2_6 \times 12 \leq 120 + y_5 + y_6$$

$$\frac{x_8}{60 \times 0.65} + \frac{x_{10}}{50 \times 0.6} + 2_8 \times 8 + 2_{10} \times 20 \leq 120 + y_8 + y_{10}$$

$$y_1 + y_7 \leq 48 \qquad\qquad x_1 \cdot 2_1 + x_2 \cdot 2_2 \geq 3500$$
$$y_2 + y_3 \leq 48$$
$$y_4 + y_9 \leq 48$$
$$y_5 + y_6 \leq 48$$
$$y_8 + y_{10} \leq 48$$

In the above attached image we have formed the LPP. Here the decision variables are following:

x1: parts produced by Machine 1 for part 1

x2: parts produced by Machine 2 for part 1

x3: parts produced by Machine 2 for part 2

x4: parts produced by Machine 3 for part 2

x5: parts produced by Machine 4 for part 2

x6: parts produced by Machine 4 for part 3

x7: parts produced by Machine 1 for part 4

x8: parts produced by Machine 5 for part 4

x9: parts produced by Machine 3 for part 5

x10: parts produced by Machine 3 for part 5

y1: overtime hours worked by machine 1 for part 1

y2: overtime hours worked by machine 2 for part 1

y3: overtime hours worked by machine 2 for part 2

y4: overtime hours worked by machine 3 for part 2

y5: overtime hours worked by machine 4 for part 2

y6: overtime hours worked by machine 4 for part 3

y7: overtime hours worked by machine 1 for part 4

y8: overtime worked by machine 5 for part 4

y9: overtime hours worked by machine 3 for part 5

y10: overtime hours worked by machine 3 for part 5

z1, z2, z3,…, z10: Boolean variable to determine if the machine is used and setup is required.

The respective code for this is present in this github repo:

https://github.com/sudeepparida3117/FalconDieCasting/blob/main/FalconDieCasting.ipynb

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3. Whenever overtime production needs to be scheduled, the traditional practice has been to schedule it on machines that are most efficient for the part being produced. This has often led to uneven overtime assignment in the sense that long hours of overtimes are scheduled on one or two machines while other machines remained idle. While this resulted in lower total overtime paid to production personnel, it often resulted in higher overall costs because of the overtime costs of the required support personnel such as administrative assistants, electricians, material handlers and quality control technicians. Their presence is necessary as long as production is in process, irrespective of the number of machines operating. Tom wondered if it would be more economical to schedule production on more machines over the weekend and minimize the total duration for which overtime production takes place. Modify your model to minimize the total duration of overtime production (i.e., maximum of the overtimes on all machines) rather than the sum of overtimes on all machines? Compare the optimal production schedule obtained with the new objective with that for question 1 and then discuss the nature of changes in the optimal solution.

Answer:

To modify the model to minimize the total duration of overtime production (i.e., maximum of the overtimes on all machines), we need to redefine the objective function and constraints accordingly. Here's an overview of the changes we would make:

- Objective Function: Instead of minimizing the sum of overtimes on all machines, we will now minimize the maximum overtime across all machines. The objective function would be to minimize the maximum overtime, which can be denoted as minmax
- Decision Variables: The decision variables still represent the number of hours of overtime assigned to each machine, but the goal is to minimize the maximum overtime, not the sum of overtimes.
- Constraints: Constraints remain similar to those in the previous model, ensuring that the total production hours on each machine do not exceed its capacity.

4. Modify your model to minimize the total cost of overtime for production and support personnel, assuming that the cost of scheduling overtime on each machine is $30 per hour and the cost of support personnel during overtime is $40 per hour.

Answer:
With the model developed in the 2nd task, we have assumed the production time is equal to the hours the support personnel put in, in overtime. The rate of production in overtime is $30 per hour while the rate of support personnel is $40 per hour.

Weeks	Total Overtime	Total Cost for Overtime Production	Total Cost for Support Personnel	
1	119.73	3591.9	4789.2	
2	92.34	2770.2	3693.6	
3	25.7	771	1028	
4	93.79	2813.7	3751.6	
5	98.91	2967.3	3956.4	
6	75.87	2276.1	3034.8	
7	76.4	2292	3056	
8	122.79	3683.7	4911.6	
9	31.07	932.1	1242.8	
10	15.11	453.3	604.4	
11	320.88	9626.4	12835.2	
12	92.34	2770.2	3693.6	
	Total	34947.9	46597.2	81545.1

5. At present, the weekend preventive maintenance effectively resets the machines so that a new setup is required to start each week's production (question 1). Tom and the maintenance supervisor developed a method by which the routine maintenance can be performed without disturbing its setup. Modify your model to take advantage of the initial setup on a machine at the beginning of a week. Assume that machines 1 through 5 are setup to produce parts 1, 2, 5, 3 and 4 respectively, at the start of week

Answer:
If the set up is not disturbed, we have removed the set up time that was needed in the initial models allowing 120 hours of regular production time. This increases the production rate in regular hours thus reducing the overtime needed for production. In python, we have used the same model we used for the 2nd task and removed the set up hours from the equations. The optimal solutions have been provided in the Excel sheet. The Python code and Excel sheet are on the GitHub link.

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6. The new maintenance method can also result in additional savings if production on any machine can be sequenced such that the machine ends a week's production setup for a part and starts the following week producing the same item. Extend your model to schedule production for two weeks at a time.

FDC is strongly committed to being responsive to customer's needs and attempts to satisfy all demand by using overtime when necessary. On some occasions, weekly production requirements exceeded FDC's capacity, even with maximum overtime. Under these conditions, FDC believes that it is critical that these shortfalls are recognized early in the process and communicated to the customer as soon as possible with a clear indication of the likely delays in delivery.

Tom noticed that during some weeks, while overtime is scheduled on some machines, other machines were not fully utilized during the regular time. Tom also noticed that in some weeks, more than one machine needed to be setup for some of the parts to meet the weekly demand. He wondered if these inefficiencies could be reduced or eliminated if FDC relaxes their long-term policy of not maintaining finished goods inventory. In that case, any excess capacity on a machine in a week can be used to produce additional units to meet the following week's demand. This may also lead to a reduction in the number of machines that need to be setup for a given part during a week.

Use the delivery schedule for week 11 in Table 1 as the new demand in week 1 and assume that a penalty cost of $3 per week is imposed for each unit not delivered on time. Assume that the cost of carrying inventory is $2 per unit per week. Modify your two-week scheduling model to permit inventory to be carried between two weeks and generate information on potential shortfalls.

Answer:

- For all the previous models, we have taken production for one week at a time. This task requires us to produce a schedule two weeks at a time. The sequencing of the scheduling must be such that one week's set up and start producing the same item.

- From customer demands, if the weekly production exceed capacity, even with overtime, the model needs to recognize shortfalls early in the process and communicate any potential delays to the customers.

- The inefficiency's caused in the model due to the company policies can be resolved by using excess capacity in one week to produce units for the next week's demand and reducing the number of machines needed for setup per part.
- To incorporate an inventory, which is not present in the existing model, we need to allow finished goods inventory to be carried to out between two weeks and consider the cost of carrying inventory which is $2 per unit per week along with a penalty cost of $3 per unit per week for any delays in deliveries.
- Through the model generated in this task, we will be able to informed decisions about production scheduling, inventory management and communicating any potential delays to the customers.

Conclusion:

The LP framework implemented is an effective technique for production scheduling optimization in Falcon die casting, and it can be implemented using both Python and Excel. It reduces overtime production time efficiently, makes better use of available resources, and offers insightful information for better operational and decision-making efficiency.

Future Work:

The future scope of this project can be:

- Provide a user interface for models in Python and Excel so that production managers can use them more widely.
- Incorporate machine learning techniques and real-time data inputs to enhance demand forecasts and make dynamic scheduling modifications.
- Examine how the LP model can be integrated with other systems for production planning and execution in order to optimize the manufacturing process holistically.

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