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Improving Workforce Scheduling in a Food Manufacturing Plant Considering Employee Skills and Daily Production Operations Using Integer Programming

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Abstract

Optimal human resource allocation is one of the key challenges in production and operations management, directly affecting process efficiency, productivity, and quality. Despite the development of various models and approaches to improve workforce allocation, many of these models have limited practical applicability due to excessive simplification and insufficient consideration of the real needs and constraints of organizations. The dairy industry, characterized by product diversity, sinusoidal demand fluctuations, the necessity of adjusting production schedules during the process, and limitations in long-term planning, represents a clear example of complex production environments that require a dynamic, flexible, and rapid model for human resource allocation. In this study, an integer programming-based model is proposed, enabling the optimal assignment of available workers to daily tasks while considering their expertise, the importance of activities, and operational constraints. The proposed model, with a simple and implementable structure in a real-world environment, generates workforce allocation plans in the shortest possible time. Experimental results across different factory shifts indicate that the resulting allocations fully align with the evaluations of production managers and experts, providing a highly effective allocation pattern. Moreover, this approach can serve as a practical framework to enhance operational decision-making in other industries with similar characteristics.

Keywords: Workforce allocation, Integer programming, Food production, Skill-based scheduling, Operational optimization.

1 | Introduction

Workforce planning in manufacturing environments is typically conducted under predefined assumptions regarding stable production activities, predictable weekly operations, and minimal disruptions in demand forecasting. Most studies in this domain rely on historical demand data to generate monthly or weekly

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forecasts, which subsequently inform production scheduling and, ultimately, human resource allocation. As Khirandish et al. [1] emphasize, the long term retention and training of personnel are critical strategic considerations. In a similar vein, Grecu et al. [2] introduce multi criteria decision making methodologies for employee assignment, focusing on individual human and skill based attributes. Azimi and Udin [3] investigate workforce allocation in urban health services; although their context is healthcare, their methodological approach, rooted in staff location modeling and demand density and coverage analysis, parallels the spatial and operational challenges found in industrial settings. Chen et al. [4] examine labor assignment in precast concrete component production, demonstrating that well structured workforce planning can significantly reduce construction time, operational costs, and error rates. Szwarc et al. [5] develop robust scheduling models for multi skilled labor allocation, highlighting how unexpected fluctuations in activity durations or employee absenteeism can disrupt entire production timelines. Romo et al. [6] argue that human resources should not be viewed merely as execution tools but rather as a strategic capital asset. A comprehensive review of the relevant literature reveals that while workforce allocation models have been extensively developed, a critical gap remains with respect to demand characteristics. Notably, none of the existing studies address the challenge of make to order production based on daily customer orders, a scenario particularly prevalent in small scale manufacturing units. In such settings, managers are often compelled to rely on time consuming, ad hoc procedures, which in turn introduce significant inefficiencies and operational friction. Furthermore, the prevailing body of research is predominantly cost minimization oriented. Although cost efficiency is undeniably important, it is not the primary concern for firms with stable, permanent workforces. For many production facilities, the core issue is rather the enhancement of labor productivity and overall efficiency. In response to these identified gaps, namely daily order variability, efficiency maximization, skill based assignment, and adherence to production constraints, this study proposes an optimization model tailored to the specific needs of manufacturing environments. The proposed framework is empirically validated through implementation and testing in a dairy production facility, where its practical applicability and performance are assessed under real world operating conditions.

2 | Research Method

A specialized examination of industrial units operating with a make to order production system reveals that such facilities require high and reliable production efficiency, one of whose fundamental pillars is workforce productivity. It is intuitively evident that each employee delivers their best performance in roles where they are distinguished from their colleagues both in terms of skill and experience. This information was collected through questionnaires administered to members of the unit's production office, and subsequently, using an importance weighting factor, was converted into an efficiency score for each employee across the three core skill categories required. The next issue concerned the number of personnel possessing these three skills required for each activity, as well as the importance coefficient of each skill within those activities, both of which were also gathered via the same questionnaire survey.

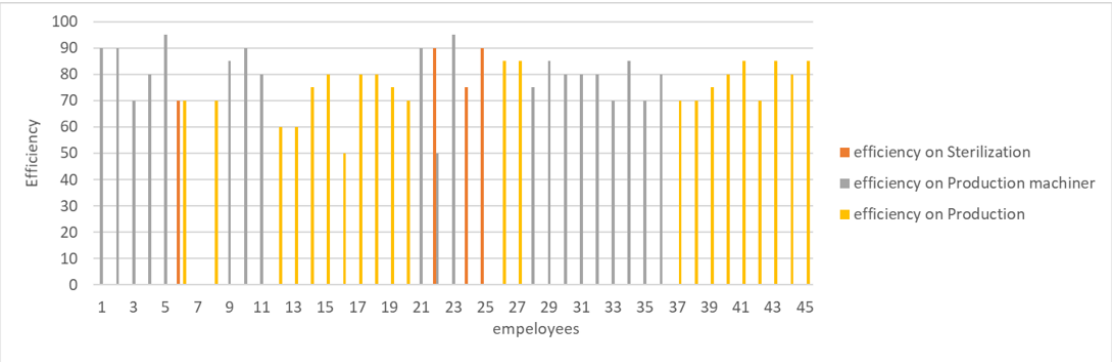


Fig. 1. Operator efficiency across each of the three core skills.

Table 1. Sample excerpt from the questionnaire on required number of personnel and skills per activity.

Operator		Machine Operator		Sterilization Operator		Production Line Processes	Entry
Number	Importance	Number	Importance	Number	Importance		
3	3	1	5			Coagulating curd	1
3	3	1	5			Coagulating cheese	2
		3	5			Pasteurization	3
1	1					Milk loading	4
		2	5			Yogurt milk production	5
3	2	1	4			Cream cheese production, 100g round	6
3	2	1	4			Cream cheese production, 100g 7×7	7
7	2			2	5	Sterilized cream production, 200g	8
6	2			2	5	Sterilized cream production, 1000g	9
8	3	1	5			Sweet pastry cream production, 500g	10
8	2	1	5			Sweet pastry cream production, 1000g	11
2	2	1	5			Sweet pastry cream production, 5000g	12
1	2	1	3			Doogh production, 900g nylon mint flavor	13
1	2	1	3			Doogh production, 900g nylon shallot flavor	14
1	2	1	3			Doogh production, 900g nylon pennyroyal flavor	15
3	2	1	4			Doogh production, cup	16
6	2	1	4			Doogh production, 1.5L mint-pennyroyal flavor	17
6	2	1	5			Doogh production, 1.5L kefir	18
6	3			2	5	Sterilized milk production, 1L full-fat	19
6	3			2	5	Sterilized milk production, 1L low-fat	20
7	3			2	5	Sterilized milk production, 200cc rectangular	21
8	3			2	5	Sterilized milk production, 200cc triangular	22
7	3			2	5	Chocolate milk production, 200cc rectangular	23
8	3			2	5	Chocolate milk production, 200cc triangular	24
6	3			2	5	Chocolate milk production, 1L	25
		1	4			Milk production, 900cc nylon, low-fat	26
		1	4			Milk production, 900cc nylon, semi-fat	27
3	2	1	4			Curd production, 250g	28

Furthermore, the list of daily activities to be examined in the production unit, along with the roster of employees present on that given day, must also be prepared. Based on the obtained information, as well as the defined start and end times for each of the daily activities under investigation, the problem can be formulated as an integer mathematical programming model aimed at maximization.

Sets:

i: Set of employees

j: Set of activities

ip: Set of employees present on the day under review

jp: Set of activities present on the day under review

s: Set of skills

j1, j2: Subsets of identical activities within the set of activities scheduled for the day under review

Parameters:

R_{is}: Efficiency of each employee in each skill

N_{js}: Required number of personnel for each skill in each activity

$START_j$: Start time of each activity

END_j: End time of each activity

C_{js}: Importance weight of each skill in each activity

H: Shift working hours

Variables:
Z: Total efficiency

X_{IJS}: Binary variable representing the assignment of each employee with a specific skill to a given activity

Equations:

$$\text{maximize } Z = \sum_{i\in ip}\sum_{j\in jp}\sum_{s} X_{ijs} * R_{is} * C_{js}. \quad (1)$$

$$\sum_{i\in ip:R_{is}>0} X_{ijs} = N_{js}, \forall_{s,j\in jp} : C_{js} > 0. \quad (2)$$

$$\sum_{s:R_{is}:C_{js}}\sum_{j\in jp} X_{ijs} * D_j \leq H, \forall_{i\in ip}. \quad (3)$$

$$X_{i,j1} + X_{i,j2} \leq 1, \forall_{i\in ip}, \forall_{j1,j2\in jp}, j1 \neq j2. \quad (4)$$

$$\sum_{s;\, R_{is}>0\,:\,C_{js}>0} X_{ijs} \leq 1, \forall_{i\in ip}, \forall_{j\in jp}. \quad (5)$$

3 | Model Description

Objective Function: Maximize the sum of the products of X_{ijs}, R_{is} an C_{js}d,subject to the condition that indices i and j belong to ip and, jp respectively.

Constraint 1. For all values of s and j belonging to jp where $C_{js} > 0$, the sum of X_{ijs} over i belonging to ip with $R_{is} > 0$ must equal N_{js}.

Constraint 2. For each i belonging to ip, the sum of X_{ijs} over the set of skills s for which both R_{is} and C_{js} exist, across all activities j within their respective time windows D_j, must be less than or equal to H.

Constraint 3. For all i belonging to ip, and for any distinct j1 and j2 belonging to jp, the inequality $X_{ij1} + X_{ij2}$ must be greater than or equal to 1.

Constraint 4. For all i belonging to ip and j belonging to jp, the sum of X_{ijs} over the set of skills s for which both R_{is} and C_{js} are greater than zero must be greater than or equal to 1.

4 | Findings

The developed model was implemented to evaluate its efficiency and effectiveness in a dairy production facility across several daily shifts, encompassing 45 operators, 44 activities, and 3 core skills. For each daily shift, the list of available operators and the list of activities scheduled for that shift, along with their respective start and end times, were recorded and incorporated into the model's dataset. Given that the model was developed as an integer programming formulation, appropriate software tools were employed for its execution. Specifically, GAMS software was used for model implementation, CPLEX was utilized as the solver, and Excel was employed for result visualization and reporting.

Table 2. List of activities with corresponding start and end times.

Activities	Start	End
1	9	12
3	8	16
4	8	16
12	12	15
18	13	16
21	9	15
31	7	14
35	9	15
40	15	17

Table 3. Sample results obtained from the implementation of the proposed modeling framework.

Operator	Activities	Skill		
		S	M	O
1	3		1	
1	18			1
2	3		1	
5	1		1	
5	12		1	
5	31			1
5	40		1	
6	21			1
7	4			1
8	21			1
9	18			1
12	18			1
15	21			1
17	1			1
17	12			1
18	1			1
18	12			1
19	21			1
21	35		1	
22	21	1		
23	18			1
23	31		1	
23	40		1	
25	21	1		

After collecting data over several days and feeding them into the model, the results proved to be highly reliable and practically feasible for implementation, both in terms of applicability and logical consistency. It is observed that all model constraints are fully satisfied, with no interference detected among activities or their respective time allocations, which in itself attests to the robustness of the developed model. It is worth noting that the model has been operational in the studied industrial unit from the time of its implementation up to the present day.

5 | Conclusion

It is evident that an integer programming model can optimize a workforce allocation problem in a remarkably short time and with exemplary precision. Given the practical application of the mathematical model developed in this research, along with the obtained results, it can be concluded that the study, having duly addressed all pertinent considerations including workforce efficiency and variable daily demand, has succeeded in producing reliable and efficient outcomes. Furthermore, with adjustments to the input data volume, the proposed model can be readily adapted for implementation across a wide range of manufacturing units.

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