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Research on the Production Scheduling System for Prefabricated Component Factories in Smart Construction

Chunxia Yang[1,*], Jie Ding[1], Zicheng Wang[1], Feng Liu[2], Xiaojun Wang[1]

[1]Department of Vehicle and Transportation Engineering, Taiyuan University of Science and Technology, Taiyuan 030024, Shanxi, China.
[2]China Railway 12th Bureau Group Real Estate Development Co., Ltd., Taiyuan 030024, Shanxi, China.

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[*]**Corresponding author:** Chunxia Yang, Department of Vehicle and Transportation Engineering, Taiyuan University of Science and Technology, Taiyuan 030024, Shanxi, China.

Abstract

In the context of smart construction, the utilization rate of prefabricated components has witnessed a remarkable surge, leading to a gradual shift from on-site fabrication to prefabricated component factories. This transition has significantly improved both working environments and production efficiency. However, despite this progress, there remains a scarcity of research focusing on the production scheduling and management of prefabricated components, particularly in relation to the ever-increasing level of automation in the production process. This poses a challenge in meeting the new demands arising from the growing unmanned nature of prefabricated component production. To address this gap, this paper takes a specific pipe pile prefabrication plant as its research subject. By analyzing the unique characteristics of the production system, we have developed and designed an interactive production scheduling system based on the Job Shop Problem (JSP) optimization approach. This system not only provides intuitive guidance for production management but also facilitates the easy revision and optimization of scheduling plans. Through this comprehensive approach, we aim to enhance the efficiency and flexibility of prefabricated component production, ultimately contributing to the further advancement of smart construction practices.

Keywords

Prefabricated Components; Production Scheduling; JSP Problems; System Development

1. Introduction

To comprehensively enhance ecological conservation and tackle the challenge of low-carbon initiatives, prefabricated components are increasingly becoming the norm in China's development trajectory, marking a significant trend in the construction of transportation infrastructure. As traditional industries undergo continuous transformation and upgrading, prefabricated component factories have gradually replaced on-site production, offering favorable conditions for migrant workers to transition into factory work, thereby significantly enhancing both the working environment and production efficiency. However, when compared to modern manufacturing sectors such as mechanical production, there remains a noticeable gap in the levels of modern production and management practices.

In international research, notable advancements have been achieved in the production scheduling of prefabricated components. Kim [1] and other scholars proposed a dynamic production scheduling model with uncertain delivery dates for the concrete prefabricated components production process, aiming to optimize the lag time. Concurrently, to enhance the traceability of the prefabricated component supply chain, they integrated a blockchain-based information management framework into the supply chain model [2]. Babagolzadeh et al. [3] mentioned that most research in the field of deadlinerelated standards assumes that order deadlines are known and remain constant throughout the decision-making process. However, real-world environments often exhibit more dynamic and complex characteristics beyond these common assumptions. Yazdani et al. [4] argued that in the trend of factory-based production of construction components, focusing solely on the scheduling of prefabricated projects ignores other crucial factors such as the impact of component production and delivery times on the implementation of construction projects. Coelho et al. [5] analyzed some shortcomings of existing algorithms and proposed a new three-stage algorithm to accommodate large-scale case studies. Hauder et al. [6] developed a new mixed-integer and constraint programming model under multi-objective constraints of time and resource balancing, which has been validated in practical engineering projects. However, these approaches have not fundamentally addressed the issue of optimal scheduling under resource constraints. Lee et al. [7] suggested categorizing prefabricated construction projects into manufacturing-driven, site-driven, and combined types, and improving the scheduling strategy based on a progress-driven approach. The focus shifted from work priorities to project scale and constraint variations. A discrete event simulation conceptual model was established, but further research is needed to utilize the model in practical guidance.

In summary, to enhance the production efficiency and optimize the layout of prefabricated component factories, aligning with the 14th Five-Year Plan's emphasis on the robust development of prefabricated buildings, this article will address the existing research gaps in the production scheduling of prefabricated component factories. It will develop a Job&Shop production scheduling system tailored for smart construction, grounded in practical engineering, to elevate production efficiency.

2. Prefabricated Construction Production System

2.1 Current Status of Prefabrication Factories

Research on Yezhen Precast Component Factory in Taiyuan, and analyze the production system characteristics. Yezhen Component Factory mainly produces precast piles, precast columns, and cement cover plates. There are three production lines: one precast component production line, one fixed table mold production line, and one steel processing production line. The main equipment on the production line includes a steel processing machine, steel cutting machine, steel bending machine, crane, air compressor, concrete mixer, tension machine, centrifuge, steam curing kettle, etc.

The production process is divided into the following steps: the steel bars are processed by the equipment first, then assembled into cages and placed in the prepared steel molds. Concrete is poured into the molds, followed by mold closure and prestressing. After prestressing, the components are hoisted into the centrifugal pool for shaping, then demolded. Finally, the demolded precast components are cured.

2.2 Pre-built Production System Features

The production system can be described as follows: in a precast component production factory, before a certain planning cycle begins, n precast component orders are received from customers and need to be allocated to the precast production line for processing.

The production process consists of 8 steps: rebar cutting, rebar bending, rebar straightening, compiling, feeding, tensioning, centrifugation, and steam curing.

In terms of the characteristics of the production process, it can be divided into parallel and serial operations. Steam curing is a parallel operation, allowing for the simultaneous curing of multiple prefabricated components. The remaining steps are serial operations, with only one order being processed in sequence at a time.

Additionally, based on the number of production resources, the operations can be classified as specific or general. Operations 6 and 7 are specific operations, requiring a concrete pouring machine for pouring and the expertise of professional technicians for defect repairs. Conversely, the other operations are general operations, akin to traditional assembly line production

The system considers the following assumptions:

1) All orders and machines are available at the start of scheduling.

2) Installation and transportation times between adjacent processes for orders are negligible.

3) Except for parallel processes, only one order can be processed by a production resource at a time for other processes.

4) Unexpected machine breakdowns and maintenance are not considered.

5) For a specific process, orders assigned to the same production resource are scheduled based on the completion time of the previous process.

6) Production operates on a 24-hour shift system for continuous production throughout the day.

3. Design of Production Scheduling System

3.1 Job Shop Production Environment

The production environment of prefabricated construction factories falls into the category of Job shop production. It involves processing different types of jobs at various workstations in a specific sequence; each job may require multiple operations at different workstations, and the order and timing of these operations can vary based on specific requirements.

The advantages of this production environment lie in its high flexibility, strong scalability, good yield elasticity, and high fault tolerance to machine failures. However, it also has disadvantages such as difficulties in scheduling and low capacity utilization.

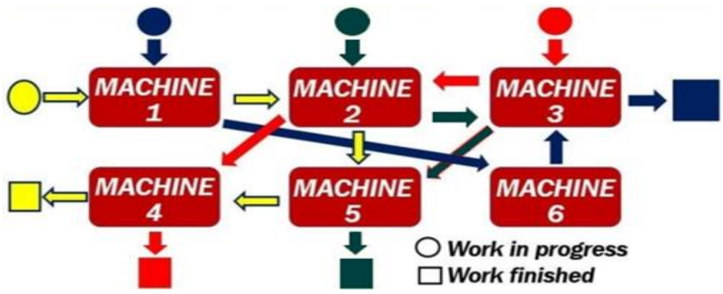

Figure 1. Job Shop Production Environment.

In the diagram, circular blocks represent the start of a job, while square blocks represent the end of a job. Different colored blocks and arrows represent different jobs and their corresponding processes. The machines labeled MACHINE1-MACHINE6 represent different workstations (devices).

When conducting production scheduling in a Job shop environment, as multiple different jobs involve multiple tasks, each of which corresponds to different equipment and labor hours, effective task scheduling is necessary to maximize production efficiency and resource utilization due to the varying operational sequences and timing requirements of each job. This typically involves addressing issues such as job sequencing, job scheduling, and resource allocation to ensure that jobs are completed on time with minimal waiting time and resource waste.

3.2 Job-Shop Algorithm Solution

The Job-Shop Problem (JSP) is a classic combinatorial optimization problem that aims to develop suitable algorithms to find the optimal solution among all feasible options. It is also a canonical discrete manufacturing optimization issue, encompassing the scheduling of a series of jobs across various workstations to minimize completion time or other metrics, ultimately achieving efficient job scheduling for maximum production efficiency.

Google OR-Tools is an open-source optimization toolkit that houses a range of algorithms and tools for addressing various optimization problems. Among these, it offers algorithms specifically tailored to the Job-Shop Problem. One such approach employs a metaheuristic algorithm based on tabu search to seek the optimal job scheduling solution.

4. Software Development

In the development of this software, we chose Python 3.11 as the programming language due to its vast array of features and robust performance, which enables it to fulfill the diverse requirements of our project. To ensure the stability and usability of our development environment, we opted for PyCharm 2023 as our Integrated Development Environment (IDE) running on the Windows operating system. PyCharm greatly enhances our development efficiency through its intelligent code editor, robust debugger, and integrated version control system.

During the implementation of the project, we relied primarily on several crucial Python modules and tools. Firstly, the PySimpleGUI module enables us to create Graphical User Interfaces (GUIs) effortlessly, making the software more intuitive and user-friendly. Through PySimpleGUI, we can rapidly design and build various interactive components such as buttons, textboxes, and dropdown menus to realize the software's functionality.

Secondly, the Pandas library plays a pivotal role in our data processing tasks. It provides robust functionalities for data analysis and manipulation, allowing us to handle and analyze large amounts of data with ease. Pandas' DataFrame data structure facilitates the convenient storage and manipulation of tabular data, while also supporting various data cleaning, transformation, and aggregation operations, greatly facilitating our data analysis work.

Furthermore, to visualize and present data, we selected the Matplotlib plotting library. Matplotlib generates high-quality graphs and charts that help us understand data more intuitively. Through Matplotlib, we can create various chart types such as scatter plots, line graphs, and bar charts to showcase data distributions, trends, and correlations.

Regarding software packaging and distribution, we utilized the PyInstaller tool. PyInstaller packages our Python code into standalone executable files, enabling the software to run in environments without a Python interpreter. This significantly enhances the portability and distributability of our software, making it convenient for users to install and use on different operating systems.

Lastly, to optimize and solve complex optimization problems, we introduced Google OR-Tools. OR-Tools offers a comprehensive set of optimization algorithms and tools that assist us in quickly building and resolving various linear programming, integer programming, and constraint satisfaction problems. Through OR-Tools, we can efficiently find optimal or near-optimal solutions, providing powerful support for our software development. The development process is illustrated in Figure 2.

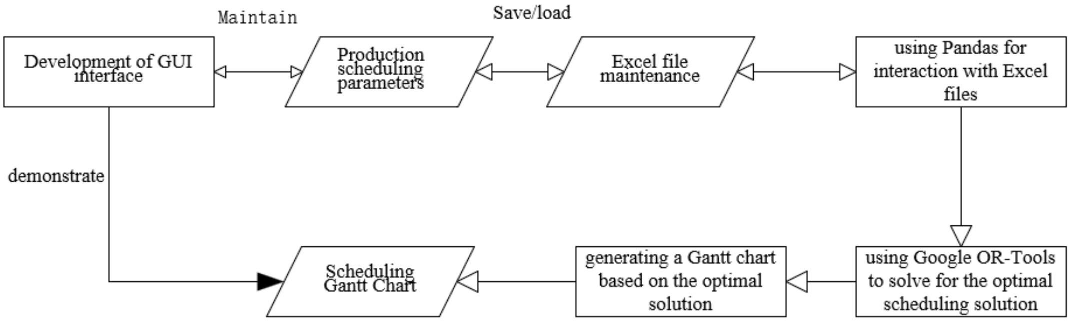

Figure 2. The flowchart of this software development.

5 Case Study Analysis

5.1 Process Elements

The prefabricated component production factory manufactures prefabricated pipe piles, prefabricated square piles, and cement slabs. The equipment used in each process and the processing time for the processes are shown in Table 1 below.

Table 1. Processing Time for Component Processes

Component Name	Processing Time per Process (hours)							
	Reinforcement Cutting	Reinforcement Bending	Straightening of Reinforcement	Cage Weaving	Material Feeding	Tensioning of Reinforcement	Centrifugal Casting	Steam Curing
Prefabricated Pipe Pile	1	1	1	2	0.82	1	1	6
Prefabricated Square Pile	2	2	1	--	1	1	--	5
Precast Bridge Slab	2	1	1	--	1	1	--	4

5.2 Production Scheduling Optimization

Integrating equipment specifications, component details, and process information into the system is a foundational step in establishing a comprehensive production scheduling framework. This meticulous data entry ensures that the system possesses the necessary insights to facilitate an optimized and efficient production flow. as shown in the diagram4.

5.2 Building Models

Based on the analysis results of CFA, it indicates that the data is suitable for analysis using structural equations. A structural path analysis model as shown in Figure 2 was constructed using software AMOS.23. Circles represent potential variables, and boxes represent observed variables. e1~e22 are the measurement errors of the observed variables, and the final outcome variables are customer satisfaction and customer loyalty.

Display the work plan in a table format, linking all jobs, workstations, and processing times for each job at each workstation in the Job shop to form a scheduling solution for optimization. The optimized solution (Figure 3) using 21 work hours. The unscheduled time before optimization takes 44 hours.

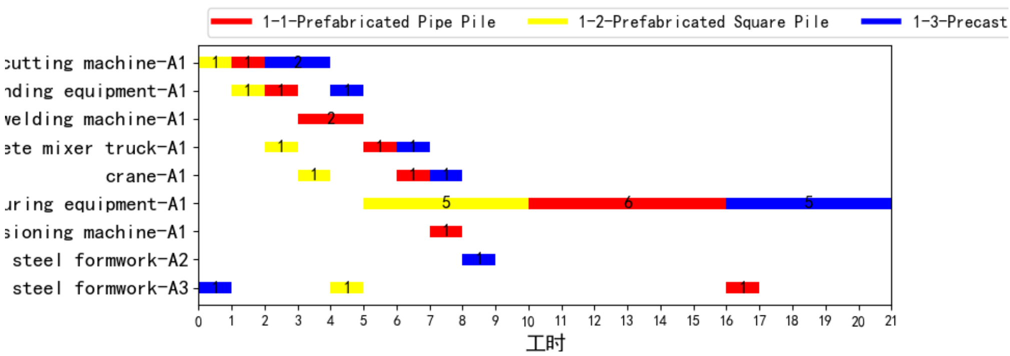

Figure 3. Gantt chart for the optimal scheduling plan.

6. Conclusion

Due to the unique characteristics of the Job shop production environment, production scheduling often faces the challenge of finding optimal solutions under multiple constraints. Although there are various algorithms and solvers available in the market that can address the Job-Shop Problem (JSP), most of them come in the form of algorithmic and tool modules, which are not readily accessible to average production managers. Additionally, the scheduling solutions obtained from these general tools are often described in text or list form, lacking the intuitive visualization necessary for effective production management. This format makes it difficult to quickly assess the quality of the scheduling solutions and even more challenging to conveniently modify and optimize them.

To address these limitations, our software is designed to maintain a comprehensive database of typical equipment, parts, and labor hours parameters. Leveraging the powerful capabilities of Google OR modules, it intelligently generates production scheduling solutions. The results are then displayed and saved in the form of Gantt charts, providing a convenient and intuitive tool for subsequent production scheduling. This approach not only simplifies the process for production managers but also enables them to visually assess the effectiveness of scheduling plans and make necessary adjustments with ease.

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References

[1] Kim, Taehoon, Yong-woo Kim, and Hunhee Cho. Dynamic production scheduling model under due date uncertainty in precast concrete construction [J]. Journal of Cleaner Production (2020): n. pag.

[2] Wang Z, Wang T, Hu H, et al. Blockchain-based framework for improving supply chain traceability and information sharing in precast construction [J]. Automation in Construction, 2020, 111(Mar.):103063.1-103063.13. DOI:10.1016/j.autcon.2019.103063.

[3] Babagolzadeh M, Shrestha A, Abbasi B, et al. Sustainable cold supply chain management under demand uncertainty and carbon tax regulation [J]. Transportation Research Part D: Transport and Environment, 2020, 80:102245. DOI:10.1016/j.trd.2020.102245.

[4] Yazdani M, Kabirifar K, Fathollahi-Fard A, et al. Production scheduling of off-site prefabricated construction components considering sequence dependent due dates [J]. Environmental Science and Pollution Research International, 2021. DOI:10.1016/j.eiar.2019.106358.

[5] José Coelho, Vanhoucke M. Going to the core of hard resource-constrained project scheduling instances [J]. Computers & Operations Research, 2020, 121:104976. DOI:10.1016/j.cor.2020.104976.

[6] Hauder V A, Beham A, Raggl S, et al. Resource-constrained multi-project scheduling with activity and time flexibility [J]. Computers & Industrial Engineering, 2020, 150(3):106857. DOI:10.1016/j.cie.2020.106857.

[7] Lee J, Park M, Lee H S, et al. Classification of Modular Building Construction Projects Based on Schedule-Driven Approach [J]. Journal of Construction Engineering and Management, 2019, 145(5):04019031.1-04019031.9. DOI:10.1061/(ASCE)CO.1943-7862.0001656.