

DEVELOPMENT OF AN ARTIFICIAL INTELLIGENCE PLANNER FRAMEWORK FOR BESPOKE PRECAST CONCRETE PRODUCTION

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ABSTRACT

Precast concrete industry is highly involved in construction projects through the supply of bespoke products. It delivers many advantages to the construction industry in terms of saving time, cost, and reducing congestion on construction sites. However, precast manufacturers are facing a substantial problem of long customer lead-time for bespoke concrete products. Most of time and effort is spent on a long production process consisting of product design, production planning, and shop floor manufacturing. Also, variations in the process due to many uncertainties, many parties and human involvements extend buffers of the customer lead-time. Lean construction concepts that are adapted for the unique production system of construction work recognize the above problem as waste and directly aim to eliminate them. Complying with the concepts, the authors have proposed an automatic planning system called artificial intelligence planner (AIP). The AIP retrieves product data from design process for the automatic planning process. In order to develop requirements and specifications of the AIP, this paper concisely describes precast design and production planning processes from a case study of a precast company. Artificial intelligence and flow-shop scheduling techniques that provide development background are reviewed. Also the components of the AIP are described. The AIP is expected to reduce the customer lead-time, assist precast manufacturers to manage changes in product requirements and/or delivery dates; therefore, the construction industry will share the benefits.

KEY WORDS

Precast production, bespoke product, customer lead-time, artificial intelligence, flow-shop scheduling, planning.

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INTRODUCTION

The construction industry outsources and receives many advantages from prefabrication and precast concrete manufacturing such as saving time and overall cost, due to enabling concurrent different production lines; increasing constructability, and reducing congestion on site due to changing from an uncontrollable work environment on site to a controllable one in factories. Precast concrete manufacturers (or precasters) are involved in a construction project team as suppliers or subcontractors who produce, deliver, and erect precast components.

Precast products used in the construction industry are both catalogued and bespoke products. Those catalogued products have been well designed and produced, like ordinary manufacturing products, in a make-to-stock fashion whilst the bespoke products are designed and produced to meet requirements of a particular construction project. The bespoke products therefore are make-to-order production style. They are unique and require longer lead-time and more sophisticated production management for precasters to coordinate with the design and construction team of a construction project.

This paper aims to propose a novel production planning system for reducing the lead-time of the bespoke products. The organization of the paper is starting from reviewing precast production process including product design process and production planning process from a case study because they take most of the lead-time. The production process review helps to understand considerations, practices, and procedures of the processes. Then, lean construction concepts are implemented to address problems in the processes and to provide sensible solutions. After that, a new methodology using data integration, artificial intelligence technologies, and a flow-shop scheduling technique is developed. Finally, the paper outlines a framework for developing an automatic production planning system called artificial intelligence planner (AIP). The requirements, specifications, and functionalities of the AIP are described. Its components are also explained.

THE PRECAST INDUSTRY

Bespoke precast production process consists of three main processes namely product design, production planning, and shop floor manufacturing. Only the first two processes concerned with generating and managing product data are briefly reviewed in this paper. The design process, which is an upstream process, has an impact on the planning process because product design is the main source of input for planning. The production processes from a case study of precast concrete façades of an office building are described as follows.

PRODUCT DESIGN PROCESS

Product design is the process of developing all product definitions. Precasters, as subcontractors or suppliers, gather the project designs from a project designer team, which are not prepared for precast work to do their own product detailed designs and they have to ensure that both architectural and engineering requirements of the project are met.

Precast designers initiate precast general arrangement drawings (PGAD). PGAD are key drawings, which demonstrate how the façade is broken down into pieces, how they are

jointed together, how they are fastened to the structure behind, and what their appearances are on the building. The important criteria for economic designs are to make precast pieces as large as practicable, and identical as many as possible in order to minimize the number of moulds and to increase repetitive work. Since precast units are cast in purpose-built moulds, effective mould-reuse helps reduce the unit cost of products. Although the iteration of mould use means cost saving, the production programme is longer due to waiting time for mould availability. PGAD are later used by many successive processes particularly precast planners use them for preparing the bill of quantities (BOQ), delivery schedule and production planning.

PRODUCTION PLANNING PROCESS

Production planning is the process that gathers necessary information to analyze and issue the production schedule, and controls the shop floor manufacturing progress. Precast planners receive product information from the design process to perform the planning process. They assign identifications to all designed precast pieces, group the similar pieces to the same product families, and decide number of moulds required. A purpose-built mould is prepared for the largest piece in the family with inserts or adjusts to reduce the mould size for smaller pieces of the same general form. This enables the reuse of moulds for several pieces.

The planners arrange a production plan regarding two constrained requirements: the current workload and the construction project schedule from contractors. Contractors could make a request of product delivery related to their construction progress on site. The planners and the contractors agree upon their own constraints to create a product delivery schedule. The precasters' current workload is analyzed and tuned along with the factory capacity whilst achieving the delivery schedule. The planners estimate manufacturing workload of a new project into the production plan. The manufacturing workload is expressed in terms of "casting hours" which are the aggregate of the number of hours for fabricating precast pieces based on the their size, difficulty of the design, and materials procurement.

The production schedule is arranged by simply applying the earliest due date rule and the experience-based estimation. The planners assign a production sequence and estimate the manufacturing time required for the products. Products with the earliest due dates are placed in the first order and the next product in this fashion.

CORRECTION AND CONTROL EFFORTS

Precasters spend substantial time and tedious efforts on preparing PGAD due to many parties being involved in the design process of construction projects i.e. architects, engineers, and/or trade specialists. In most cases, construction projects do not have enough time to allow each party to finish their design in turn. Rather these parties develop the project designs in a concurrent manner. Precasters usually suffer from incomplete design information that comes from the project designer team (both architects and engineers). Precasters have to use that information but they spend several man-hours in order to check for any mistake, mismatch, missing, or ineptness in it. Precasters are prone to many changes that might occur from the project designer team at any time. Precasters absorb many risks from those changes and incorrect design information.

In addition, a precast production schedule can be revised many times. Not only the project design team can affect the precast production planning but also the contractors who directly request the product delivery. The construction schedule is revised quite often due to many variations on site and consequently the delivery schedule is revised. A change in product delivery dates causes disturbances to precasters, as they have to reallocate their constrained resources over the current workload and reschedule their production plan. These changes consume time and efforts of the planners and causes waiting times of the other successive procedures, and they fluctuate the optimum resource allocation level of precasters. Moreover, there is no guarantee that the earliest due date rule provide the optimum production sequence.

LEAD-TIME CHARACTERISTIC

Precasters are facing the problem of a long production process lead-time. It is necessary that definitions of production time be clearly understood. Hopp and Spearman (2001) defined that cycle time is a random variable relating the time it takes for a job. Unlike cycle time, lead-time is a management constant used to indicate the anticipated or maximum allowable cycle time for a job. Customer lead-time is the amount of time allowed to fill a customer order from start to finish. In a make-to-stock environment, the customer lead-time is close to zero because products are ready to serve when customer arrives. In a make-to-order environment, the customer lead-time is the time that customers allow the company to design, produce, and deliver an item. For the case when variability is present, the customer lead-time must be greater than the average cycle time in order to have acceptable serviceability.

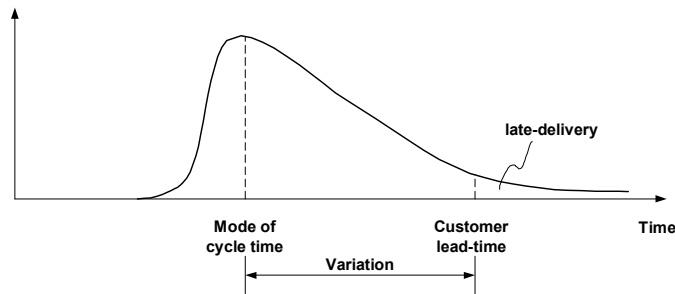


Figure 1: Cycle time distribution (reproduced from Vandaele and De Boeck 2003)

Lead-time is characterized by an asymmetric distribution, mostly skewed to the right (Vandaele and De Boeck 2003). If something intervenes in the production system, the impact on the customer lead-time is more likely to extend time rather than to decrease it. Remedies to those interventions might be rework, idle waiting time, congestion, or correction. The longer lead-time means cost to the precasters. The large right side variation in Figure 1 shows that the precasters are not good at rectifying a confrontation, and their production system is not sound. Moreover, the precasters lose their competitiveness from a longer customer lead-time. Two possible ways to reduce customer lead-time can be to shorten (mode of) cycle time and to narrow the variation.

THINK 'LEAN'

Lean construction concepts have evolved from the lean production system in the automobile manufacturing at Toyota led by engineer Ohno (Howell 1999). The concepts aim to eliminate all investigated waste using continuous improvement strategy toward an ideal waste-free production system. However, construction and manufacturing are different. Some might say that construction is more unique work with less repetition, so there are fewer advantages from learning curve or fewer chances of improving the routines; more complex organization with highly uncertain environments that means it is difficult to plan and control the project. Construction is likely to produce more waste so it really needs lean concepts.

WASTE

Lean concepts perceive waste in the production process as any resources that are spent on the process but neither adds value to the final products nor conforms to the customer requirements. Waste can be quantified in terms of time, cost, and quantity. Formoso et al (1999) have classified waste in the production process in many different forms i.e. overproduction, overqualification, waiting time, transportation, inefficient processing, inventories, unnecessary movement, defects (under qualification), and others. In terms of time resource, Koskela (1999) elaborated waste in the cycle time in the following equation.

$$\begin{aligned} \text{Cycle time} = & \text{processing time} + \text{inspection time} + \text{waiting time} \\ & + \text{transporting time} + \text{correction time} \end{aligned}$$

Only processing time adds more value to final products, the others do not. Lean concepts are suggested to shorten the cycle time by improving the efficiency of the processing and by eliminating non-value-adding times that are inspection time, waiting time, transporting time, and correction time. These non-value-adding times are consequences of the variations in the processes as depicted in Figure 1.

Indeed, Precasters, as serving the construction industry, are encountering long customer lead-time due to long cycle time for manual production processes (focusing on product design and production planning) and long buffer time for anticipated variations. Since it is difficult to predict the number of changes from imperfect project designs and uncertain product delivery schedules, but every change means repeating the manual production process. Precasters have to set a large buffer time for that. Therefore, this study considers waste in the precast production process from repetition of manual correction efforts caused by changes in the precast product design and the production planning.

IMPROVEMENT

Koskela (1999) suggested that construction could be conceived as a prototype (one-of-a-kind) production, which normally is accomplished by consistently debugging errors in design and production plans. There is little opportunity to learn and thoroughly correct designs and plans from a completed project for reuse on a subsequent similar project. Therefore, imperfect designs and unsound construction plans are quite common, and it is more likely that the whole supply chain including precasters would also interfere with changes as the debugging attempts. The improvement issue is how to relieve those efforts and time, and/or

reduce the chances of occurrences. Two research studies that aim to improve the precast concrete industry are reviewed below.

The first one is from the Lean Construction Institute. Ballard et al (2002) introduced a new production management approach called 'decoupling buffer' for precasters. The decoupling buffer is used for absorbing the variations of customer orders and shielding precasters from producing unwanted products. The strategy is to divide the manufacturing process into two stages: pre-manufacturing and final products manufacturing. Precasters are suggested to prepare production information, and pre-manufacturing elements rather than straightaway manufacture the final products. Only when there is a 'pull' from near order, probably in weekly time, prior to delivery dates, the final products are made.

The other ongoing research is being conducted by the Precast Concrete Software Consortium (PCSC, 2001). PCSC are developing an automated, comprehensive design system for precast industry. The system aims to automate precast design and the drafting process. It also assists the precast designers by combining architectural, engineering, and precast manufacturing designs together in one attempt. That means all three concerning aspects would be considered at the same time. This system is expected to reduce mismatches in the designs and the customer lead-time spent on precast design and drafting work.

Apart from that, this paper outlines the research that aims to reduce the efforts and time for precast production planning by proposing the AIP. The main objectives of the AIP are to integrate data from the design to planning processes by eliminating paper-based data; to reduce tedious human efforts for repetitive work on correction or revision of planning; to improve production planning method by using flow-shop scheduling technique; and to generate the production schedule automatically for the precast manufacturing factory. By preparing product designs, the AIP system retrieves all relevant product information, analyzes it with all conventional planning considerations, and automatically outputs a production schedule. The AIP uses the flow-shop scheduling technique to model the precast manufacturing process and to optimize the schedule. The AIP is anticipated to replace human interpretation and intuition efforts for production planning. Precasters also could revise the design or reschedule the plan faster with fewer exertions, as the changing information is perceived by the automated system can amend the other relevant information at one time.

The AIP system implements the methodology to reduce customer lead-time for bespoke precast products. The cycle time for production planning is reduced by the automation and the variation is decreased by releasing human involvement. Moreover, the AIP could be integrated with the PCSC's system to provide a completed integration system of precast product design and production planning.

ARTIFICIAL INTELLIGENCE

The planning process can be automated by employing algorithms that have the ability of processing data like human intelligence. The techniques called artificial intelligence (AI) have been introduced to the construction and manufacturing industries for many decades. Their applications and usefulness are presented in many research studies. Two AI techniques that are selected to develop the AIP are the genetic algorithm (GA) and the artificial neural networks (ANN). Some of their applications and potential to be applied on the AIP are briefly described as follows.

PRECAST FLOW-SHOP SCHEDULING WITH GA

The precast manufacturing process mainly consists of six routine tasks i.e. mould assembling and oiling; reinforcement cage, mosaic, tile (or other embedded parts) installing; concrete placing; curing; mould stripping; and product finishing. Precasters produce their various designed products with these tasks where a different specialized crew performs each of them. Leu and Hwang (2002) and Chan and Hu (2002) have modeled the precast manufacturing process on the basis of flow-shop scheduling problem that is the production scheduling of mix products package on different workstations (which is well known as m machines and n jobs). The precast manufacturing process was modeled into mathematic functions with some constraint functions to reflect a real situation. The aim is to solve the modeled problem by searching for the production sequence that gives the optimum total manufacturing time (usually called 'make-span time').

Previous research has been dedicated to improve the optimization technique and to model the problem properly. In recent years, the optimization technique has evolved from the heuristic algorithm to GA and it has been suggested that GA gives better results than the earliest due date rule or other heuristic rules (Chan and Hu 2002). The important scheduling criteria can be included into the model to form the multi objective function such as to satisfy delivery schedule, to minimize the stock of final products, and to minimize the product late-delivery. However, many assumptions have been made in order to simplify and possibly model the precast manufacturing such as precast moulds are infinite resources without considering repetition or type.

This research refines the assumptions of the past research to make a more realistic flow-shop model for bespoke precast production. Firstly, moulds are scarce resource and purpose-built for particular product families. Moulds will be occupied at the beginning of the mould-assembling task and released at the completion of the mould-stripping task. Any following job needs to wait for its mould type available, and then it can start the mould-assembling task. This is a constraint for arranging a production sequence. Secondly, the tasks are classified into two types namely preemptive and non-preemptive works. All tasks are preemptive except concrete placing and curing are non-preemptive works. Once the non-preemptive work starts, it must be sustained until completed. Although concrete-placing and curing tasks are non-preemptive, they are different in details. Concrete-placing task must be finished within working time or plus overtime if overtime work is allowed. If it cannot be finished, the task is considered to start on the next working day. Concrete-curing task is non-preemptive and start immediately after the concrete-placing task, which is its predecessor.

Thirdly, time spent to complete the tasks of any precast piece is called the processing times and are not deterministic. They depend on the difficulty of the product design and the manufacturing environment. Another AI technology, ANN, used for determining the processing times, the inputs of the flow-shop scheduling, is described in the following section. The precast flow-shop scheduling with GA is integrated to the AIP to generate the automatic production schedule.

ESTIMATION AND CLASSIFICATION USING ANN

ANN attempts to model the brain learning, thinking, and retrieval of hidden information or interrelationship of data and associative recognitions. ANN are biologically inspired; that is they are composed of processing elements that analogously perform the most elementary functions of the biological neurons. These elements are then organized in a way that is similar to the anatomy of the brain. They can be trained to learn from experience, generalize from previous examples to new ones, and conceive essential characteristics from inputs containing irrelevant data (Wasserman 1989). ANN has the capabilities of generalization, fault tolerance, adaptive and associative performance, ability to perform dynamic and real-time functions, ensure their appropriateness for many practical applications in construction (Moselhi et al. 1991). Applications of ANN in construction include construction cost estimation (Adeli and Wu 1998), optimization of mark-up estimation (Moselhi et al. 1993), estimation of construction productivity of earthwork (Chao and Skibniewski 1994), and prediction of hoisting times of tower cranes (Leung et al. 2001). Moreover, Soibelman and Kim (2002) applied ANN in a classification problem. By training the networks with some concerning factors, they could predict whether the project would delay or not.

Since bespoke precast products are varied in shape, reinforcement, materials, etc. The differences of them specify different processing times. The more difficult design or poorer working environment the more time consumes. There are some possible factors that indicate the difficulty in manufacturing a product of a particular design. How much each of these factors influences the processing times might be very difficult to explicitly explain or reveal. Therefore, this research applies ANN for being a learning tool. ANN for the precast production requires some sources of information from product designs, and production daily-reports. Apart from many available ANN models, the multiplayer perceptron (MLP) has been selected. This model type is simple but practical for various kinds of input/output map although it is slowly trained and required a number of training data. The perceptrons are layered feedforward networks typically trained with static backpropagation. The model has three layers including an input layer, an output layer, and one hidden layer.

MLP/ANN is trained by a set of input data and a set of output data. After being training, the networks memorize the pattern of the relationship between the input data and the output data. This pattern must be tested and evaluated whether to use or to retrain it. The pattern is used for estimating a new set of output data from a new set of input data. A set of input data is categorized into three groups namely product dimension, material, and working environment. Dimension factor includes height, length, width, base area, surface area, dropping area, volume, weight, number of curve, number of angle, and number of block-out. Material factor includes concrete water-cement ratio, strength, slump, tiling area, weight of reinforcing bar, number of different bar-shape, bar size, and bar spacing. Working environment factor includes manpower and working area for the tasks. A set of output data includes the processing times of the tasks and the product family. Totally, there are 35 perceptrons in the input layer, and 7 perceptrons in the output layer.

ARTIFICIAL INTELLIGENCE PLANNER

SYSTEM SPECIFICATIONS

The AIP is aimed to be able to perform all basic tasks of the precast planners. Those tasks are such as grouping precast pieces, deciding number of moulds, estimating the processing times of all manufacturing tasks, arranging job sequence, and allocating production resources. The AIP retrieves input data from many types of documents, i.e. product designs in CAD format, BOQ, delivery schedule, current workload, shop-floor daily report, and then to automatically generate production schedule or to update the schedule. The AIP has to consider the planning criteria in order to keep producing a consistent preferable schedule. The criteria are such as to satisfy delivery schedule, to minimize the inventory of final products, to minimize late-delivery, to minimize total idle waiting time of the crews, to maximize reuse of moulds, to stabilize the resource allocation, etc. Therefore, the AIP needs a system structure that is capable to retrieve the relevant inputs, process data, and present the outputs.

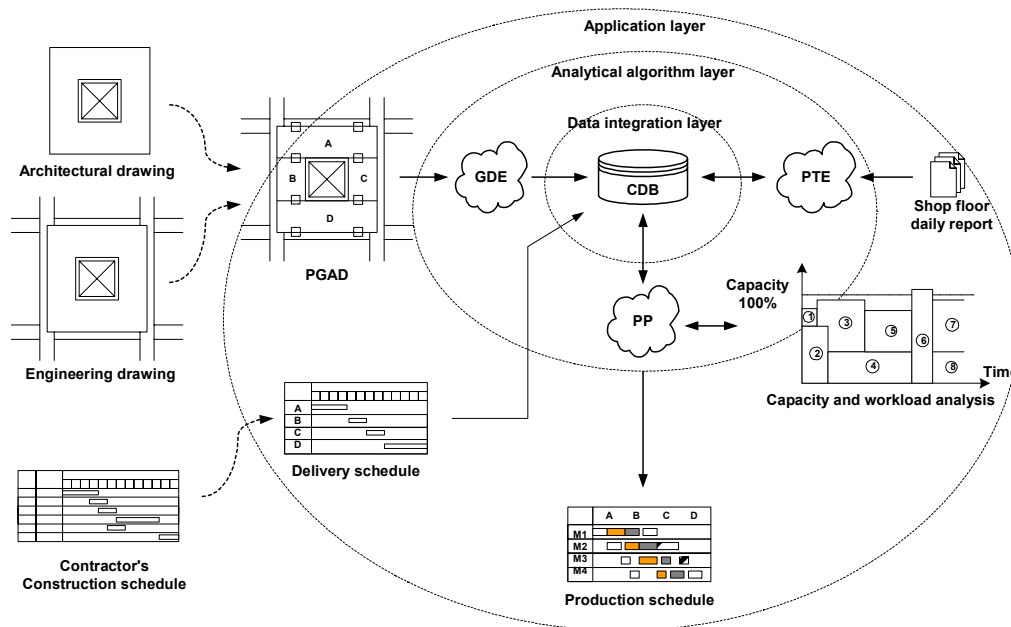


Figure 2: AIP's components

COMPONENTS OF THE AIP

Planning is all to do with placing activities on the time axis. Planners have to decide on the 'what' in terms of the 'when' (Vandaele and De Boeck 2003). Production planning, therefore, is an arrangement of what is going to be produced and when it should be produced. This definition gives two concerns about what and when. 'What' means information about the product. It could be the product itself and all required materials and resources. 'When' means the time to produce, at that time the company resources have to be utilized and constrained by the time that the product has to finish. 'When' is constrained by limited

resources and product due dates. The challenge of making a production plan is that there are many alternatives to arrange the plan but there should be a good mechanism to select the best out of them. The best plan should be quantified by the cost of the production program that the best plan should give the least cost to the company. By these facts, the AIP consists of four components in order to perform the planning process. They are namely: central database (CDB), graphic data extractor (GDE), processing time estimator (PTE), and production planner (PP). Figure 2 shows the components of the AIP.

Central database (CDB)

CDB is responsible for supplying data needed in the production planning and being data storage. It stores important descriptions of products in both terms of 'what' and 'when'. CDB is an infrastructure of the automatic system AIP. When the design process generates new data of a precast piece, these data will be recorded in CDB. CDB retrieves every product due-date from the product delivery schedule. CDB supplies required product information to the planning process. Also, CDB records output data from planning and these data are used as a previous reference when the plan is revised. In this way, data for planning are integrated and standardized throughout the processes. CDB provides the accessibility to retrieve, modify and record the data to the other components. The time that used to spend on inputting and re-inputting paper-based data can be reduced. CDB is developed in a proper data structure using a relational database system, which provides a practical and comprehensible database. Data transfer between CDB and the other components could be secured.

Graphic data extractor (GDE)

GDE is responsible for supplying the information about 'what' for the AIP. It is an embedded VBA (Visual Basic for Application) on the CAD software (AutoCAD). Precast products are typically drafted on two-dimensional CAD drawings, which are combined with many sets of lines and layers without the meaning of products or objects unless they are interpreted by human. GDE transforms those sets of lines and layers into system interpretable objects. Then, the information of the drawing objects, which represent the precast products, is extracted and sent to CDB in order to record it. The AIP recognizes the identity of a precast piece by referring to a name of the drawing objects. GDE also can total number of pieces by each product family and calculate total quantity of required materials or constituent parts of the products. It helps release the human efforts for preparing a bill of materials of the products. In other words, GDE translates CAD formatted data to CDB formatted data and determines the production workload for the AIP.

Another function of GDE is to classify the products into product families. GDE uses ANN for analyzing the similarity or the difference of the products. This ability of GDE gives a decision on how many moulds precasters should prepare with regard to the number of classified product families.

Processing time estimator (PTE)

The processing times for manufacturing tasks of the precast products are important inputs and have to be estimated before conducting flow-shop scheduling and preparing the

production schedule. PTE estimates these times from past data of product designs and their processing times, received from CDB. The other source of inputs comes from the shop-floor daily report. The report shows the actual processing times that have been used and the actual working environments. These data are treated as the training data for ANN. PTE utilizes ANN algorithm then constructs the pattern of ambiguous relationships between the processing times and the influencing factors, which are derived from the product designs, and working environment. This pattern will be used for estimating the processing times of new designed products of new project. The new estimated times produced by PTE are stored in CDB. PTE provides important inputs for the AIP since the durations of the tasks for the flow-shop scheduling are the important parameters that indicate the reliability of the schedule.

Production planner (PP)

PP has two responsibilities to do for the AIP. It assigns the starting time and the finishing time of manufacturing processes of the products. Also, it arranges the manufacturing sequence for the products. Thus, PP provides the decision of 'when' is the suitable time to produce a particular product. PP consists of two functions: workload analysis and schedule optimization. The workload analysis is conducted by combining three important information types i.e. the current workload, the new workload, and the constraint of resource capacity of the companies. The current workload is the previous production plan that can be retrieved from CDB. The new workload is the requirement of production resources for manufacturing the ordered products. From the factory's limited resources, it is necessary that the maximum capacity of the manufacturing be evaluated. The analysis will show the availability of the resources for the new workload. Therefore, PP can generate all possible alternatives of the production schedule. To function the schedule optimization, PP applies GA to the flow-shop scheduling model. PP searches through possible schedules and selects the optimal or near optimal one out of them. Finally, PP gives the result with the production schedule.

CONCLUSION

This paper has presented the precast concrete production process particularly focusing on product design and production planning, and the problem of long customer lead-time. Lean construction concepts have been used for comprehending the problem and guiding the methodology to solve it. In order to ease the effort for production planning and to improve the planning process to give a better production schedule, the paper has proposed an automatic planning system called the artificial intelligence planner (AIP). The related available AI and flow-shop scheduling techniques that help develop the AIP have been reviewed. They are flow-shop scheduling with GA, and estimation and classification with ANN. However, in order to tackle the specific problem of precast industry, these techniques have to be specifically modified and applied. The paper has outlined the specifications, requirements and functionalities of the AIP with its components. The AIP consists of four components namely central database (CDB), graphic data extractor (GDE), processing time estimator (PTE), and production planner (PP). All components perform different tasks but automatically interact with each other to fulfill the functionality of the AIP. The AIP is anticipated to help decrease customer lead-time for bespoke precast concrete production.

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