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KEYNOTE

Simulation-Based Optimisation Using Simulated Annealing for Crew Allocation in the Precast Industry

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Abstract

The increasing complexity of solving crew allocation problems in a number of labour-intensive industries has led them to require more sophisticated and innovative allocation systems to satisfy such requirements. The aim of this study is to develop an innovative crew allocation system that can efficiently allocate possible crews of workers to precast concrete labour-intensive repetitive processes in order reduce the allocation cost and achieve a better flow of work. As a part of the methodology used in developing Crew Allocation System 'SIMSA_Crew', process simulation is used to model and imitate all production processes involved and Simulated Annealing is then developed to be embedded within the simulation model for a rapid and intelligent search. A Dynamic Mutation operator is developed to add more randomness to the searching mechanism for solutions through solution space. The results showed that adopting different combinations of crews of workers had a substantial impact on reducing and minimising production cost.

Keywords: Simulated annealing; process simulation modelling; multi-layered crew vector; crew allocation problem; precast industry

1. Introduction

Labour-intensive industries require a substantial number of human labourers in order to produce their final products. A number of manufacturing system layouts in such industries are designed to involve a number of repetitive parallel production processes. Skilled labourers and experienced supervisors should be properly utilised to carry out the required production activities. The precast concrete products industry is one of the labour-intensive industries in which a number of different skilled labourers are required during the manufacturing process, which provides the required products and services to the construction industry.

The increasing cost of skilled labour in the precast industry drives production planners to improve productivity and hence decrease the total production cost. In order to improve productivity in the precast labour-driven production facility, a proper planning/allocation of the workforce is vital. The proper allocation of labourers will eventually lead to minimisation of waste and ensure a better flow of the work.

Production planners seek to achieve the best allocation of resources in their production facilities. This type of problem is complex, due to the large array of different possible allocations. The allocation problem can be called a complex combinatorial problem and the ‘classical problem solving’ techniques cannot be used to obtain satisfactory results.

The lack of innovative tools for crew allocation in the precast labour-intensive systems motivated this research to develop and test an advanced crew allocation system that can assist production planners in the precast industry, in order to improve the performance and efficiency of labour-intensive manufacturing systems. The proper allocation of crews to processes will decrease associated labour costs, reduce process-waiting time and subsequently improve the overall productivity.

This study presents an innovative crew allocation system named “S_MLSA” which is specially developed for the efficient allocation of crews of workers to labour-driven processes in the precast concrete industry, so that Process Simulation and Artificial Intelligence technologies are integrated together to produce a sophisticated hybrid crew allocation system. This hybrid system has been initiated after reviewing related literature and identifying gaps in knowledge in the current literature related to the subject area. A sleeper precast concrete manufacturing system (‘sleeper’ is one of the precast concrete product families and can be defined as a rectangle precast component for use as a base for railway tracks) is considered as a case study to test the concept of Multi-Layered Simulated Annealing.

In order to solve the labour allocation problem in the precast industry, the proposed “S_MLSA” system seems to be a promising and useful tool to solve the allocation problem. In this work, it is proposed that the embedding of a search engine such as Simulated Annealing within a process simulation model can assist production planners in identifying the best crew allocation plans in their production facilities.

2. Research Problem: Labour Allocation in the Precast Industry

Crew is a collection of workers; each worker, depending on his/her skills is able to accomplish the required job at a different level of productivity or process time. In the precast manufacturing system, a crew allocation problem appears when the formation of any crew involves shared workers working on simultaneous similar/different processes. This type of labour sharing can cause process-waiting times, labourer idle times, low resources’ utilisations, a disturbed work flow and subsequently high allocation costs. Since a parallel or sequential similar/different processes structure of a manufacturing system is pre-specified, the involvement of shared workers can be required in one or more processes.

This type of problem becomes more important when there is a significant allocation cost. This is caused by shared workers being allocated to more than one process and being required at same/different times, dictated by the sequence requirements of similar labour-intensive operations. In order to minimise labour allocation cost, an optimal/near optimal crew allocation plan is required in any labour-intensive facility. An appropriate crew allocation plan, which has to be selected between other plans, satisfies minimum allocation cost.

3. Literature Review of Simulated Annealing-Based Resource Allocation

Simulated Annealing has been used in resource planning and scheduling (Kuo, Liu, and Merkley's 2001, Chen and Shahandashti 2007, and McCormick and Powell 2004), resource allocation problems (Abdullah Zainuddin, and Salim 2008), Crew Assignment problems (N. Sumarti 2012), Pareto Simulated Annealing in scheduling problems (Hamm, Beißert, and König 2009), Multi-Site resource allocation (Aerts and Heuvelink 2002), Scheduling optimisation (Cave, Nahavandi, and Kouzani 2002), and Sequencing and resource allocation problems (Nussbaum, Sepulveda, Singer, and Laval 1998). There is a knowledge gap in terms of focusing on applying simulated annealing to solve crew allocation problems that contain multiple shift patterns, constrained labour availability and multi-skilled worker levels.

4. Development of Simulation & Simulated Annealing Models

4.1. Simulation modelling: the modified decomposition algorithm

In this section, a modified decomposition simulation methodology was presented in order to develop the simulation model. Using this methodology, after problem definition, the problem is decomposed into a number of sub-problems in order to facilitate investigation, modelling and analysis of each sub-problem, after which a simulation process of each sub-problem was required, to produce sub-models. Each sub-problem was then verified to check whether or not the modelling process logic of the sub-problem was conducted correctly. If not, then the simulation process was reviewed and compared with the logic of the sub-problem. After verifying each sub-model, a validation process took place to ensure that the simulated sub-model accurately represented the real problem. A verification process was utilised to ensure that the simulation sub-model produced accurate outputs.

4.2. Simulated annealing model formulation

In the developed model, Simulated Annealing creates a new solution by modifying only one solution with a local move. A special mutation operator dubbed Probabilistic Dynamic Mutation (PDM) was used to add the required randomness for the searching process. The optimisation loop performs a random perturbation on design variables, whose manipulation coefficient (probability of mutation) is defined by the system "temperature". The system temperature is initially high and cools down as the process evolves converge to an optimum solution.

$$Tk+1=\alpha Tk \qquad (1)$$

where:
$Tk+1$ is the temperature at the next iteration
$0< \alpha <1$
k is an index that indicates the iteration step

The worst solutions are accepted with a probability p = exp (-df/T), where df is the increase in objective function and Tk is the system 'temperature' irrespective of the value of the objective function. Thus, this probability of acceptance is high at the beginning and decreases over the course of optimisation process. The process finishes when the temperature reaches some determined value or the objective function variation does not suffer relevant changes with perturbations of the variables. The structure of the simulated annealing algorithm addressed by Busetti (2003) was tailored to be able to solve the aforementioned crew allocation problem (see Figure 1).

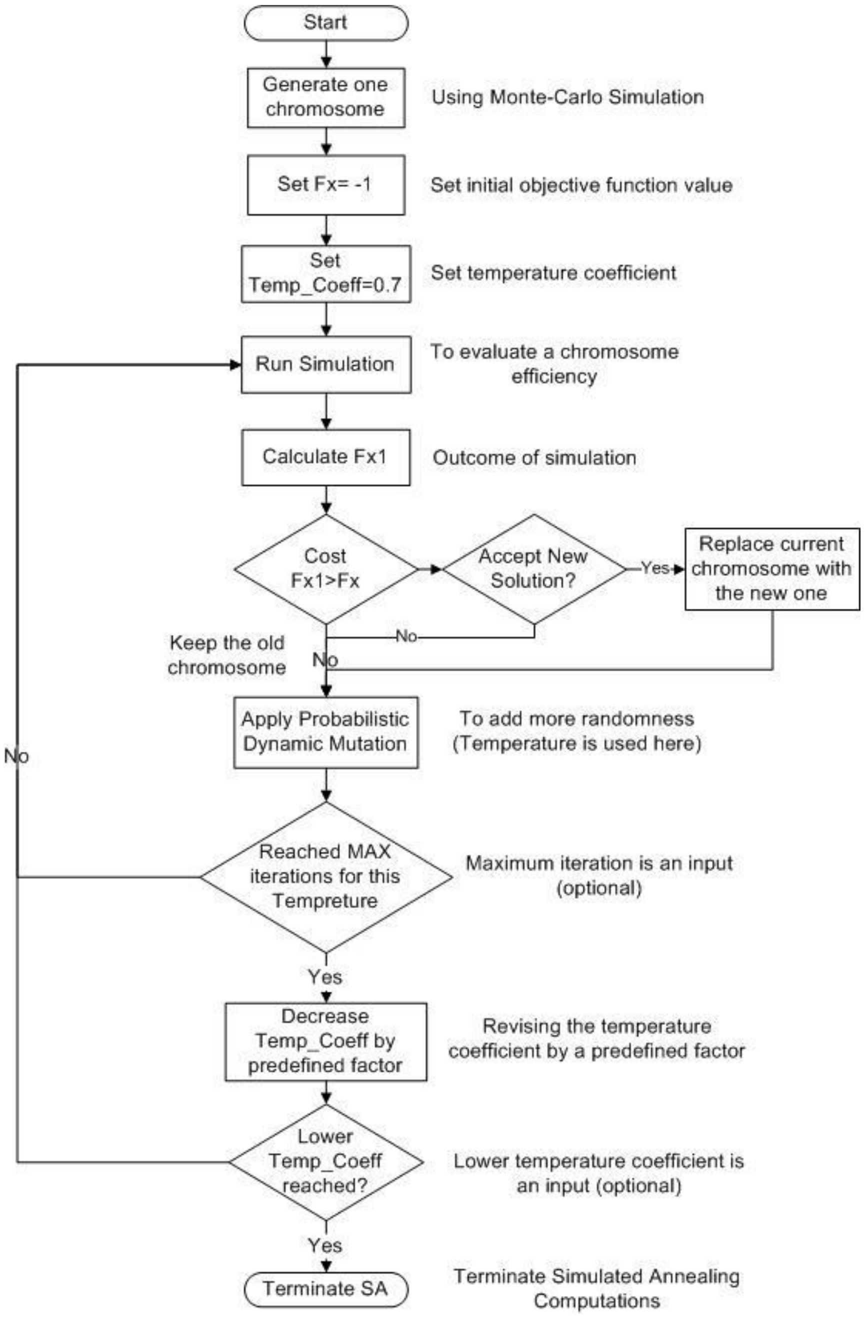

Figure 1 The simulated annealing algorithm (modified from Busetti, 2003)

As noted in Figure 1, the process starts by generating an initial input set (crew vector) using Monte Carlo simulation. Before running the simulation module, both initial values of objective function and temperature coefficient are defined. After running the simulation, the resultant objective function value calculated by evaluating inputs set in terms of allocation plan is then compared with the initial objective value. As mentioned earlier, worst solutions are accepted with a probability $p = \exp(-df/T)$. If these solutions are rejected then they will be replaced by more promising ones. Inputs of the resulted vector are then manipulated by applying the PDM strategy. The developed simulated annealing algorithm runs through predefined number of cycles. Once the specified number of training cycles is reached, the temperature could be lowered. If the temperature is not lower than the lowest temperature allowed, then the temperature is lowered and another cycle takes place.

The decision variables are placed in a row vector (string) called a crews vector. The crews vector has a number of elements (inputs) representing the number of variables. A crew vector structure has been designed to suit this type of problem. Crews vector representation for crew allocation problem is presented by Al-Bazi et al 2010.

4.2.1. Probabilistic Dynamic Mutation (PDM) strategy

In this type of mutation, n random numbers are generated to be associated with each input, a vertical mutation taking place to swap or alternate subsequently n input(s) of the selected crews vector with its set of alternatives from the multi-layered pool of crews' alternatives after satisfying the condition: If the probability of mutating an input ≤ random number associated with that input then mutation of that input is possible. The probability of mutation (equal to Temp_Coeff) can decide the number of exchanged inputs. Selected inputs can be mutated with its respective crew pool 'crew alternatives pool' using Monte-Carlo sampling. This type of mutation strategy can provide an equal chance for all inputs to be exchanged with the opposite alternative inputs.

5. Case Study

In order to analyse the capability of the system, a real life case study was developed for one of the largest sleeper precast concrete manufacturers in the UK. The experimental design consisted of developing a number of allocation plans to be evaluated through simulation. The SA engine suggests a possible set of allocations of crews to processes, which can be considered as an allocation plan. The best suggestion for allocation plans can be obtained by identifying the best parameters of the allocation system. In order to improve the searching process for promising solutions, optimisation parameters were set after a number of experiments, as several sets of different probabilities were attempted without any significant effects. The following well-tuned settings were used: the temperature equal to 70, a decrement of 0.01 and 20 iterations at each temperature. The stopping condition is satisfied when the lower temperature coefficient is reached. A comparative study of the current assignment and the optimised one was conducted. The improvement that the proposed allocation system added in terms of reducing allocation cost is demonstrated in Figure 2.

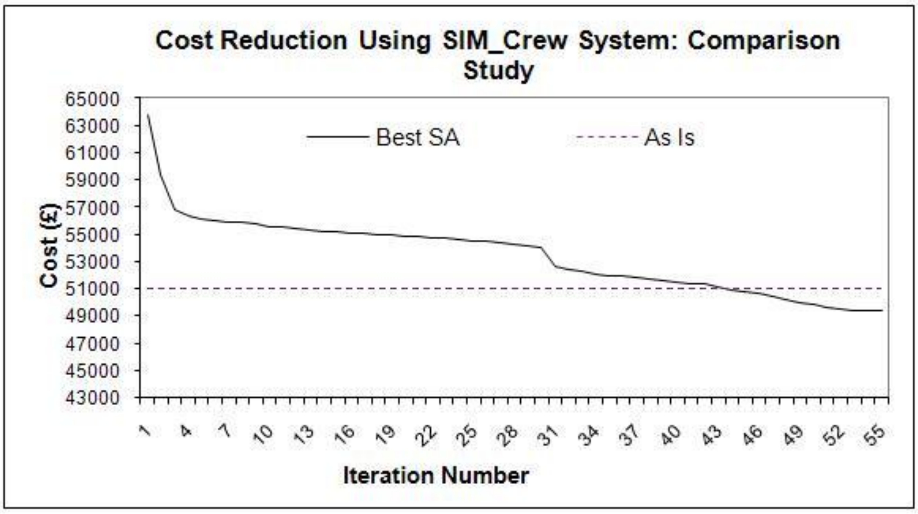

Figure 2 Cost reduction using "S_MLSA" system

Figure 2 shows that two significant cost drops take place after the 1st and 30th iterations. The SA dynamic probabilistic operator has successfully explored more promising solution areas in the aforementioned iterations. After 52 iterations, allocation costs tend to have no improvement. This best scenario drove the allocation cost to be equal to £49,062 (actual cost is £51,115) and achieving a return of 4.016% (about £2053 per ten working days).

6. Conclusion

The method of integrating process simulation with SA is presented in this work. The simulation model was successfully developed to imitate the precast manufacturing system. SA showed noticeable ability in searching and suggesting promising allocation plans to be evaluated by the simulation model. As a further development of this research different levels of priority (High, Medium, and Low) can be included in the allocation process, especially if they have a significant influence on overall system performance.

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