Fuzzy Inference based Optimization Mechanism for Construction Computer Simulation System

Nai-Hsin Pan, Ming-li Lee and Kuei-Yen Chen

Abstract— **The study proposed a dynamic simulation model with a proposed fuzzy inference-based optimization mechanism to develop an artificial intelligence-based simulation system for multi-objective optimization and to search the optimal resource allocation strategy under dual goals of time/cost tradeoff for the Movable Scaffolding System (MSS). The study analyzes the MSS model with the proposed optimization system to verify the accuracy and applicability of the proposed system via a case study. Through the human thinking model decision making module, the optimized decision basis can be quickly searched to further meet actual conditions and to enhance academic value and application of resource combinations optimization. The most suitable resource combination after applying the proposed optimization module with fuzzy inference mechanism obtains solutions for the actual situation. After model test, the optimized resource combinations using the proposed optimization module can enhance the busy rates of each resource and improve the overstock status of the material during simulation to achieve the objectives of reduced cost, efficient work schedules and enhanced productivity.**

Keyword: computer simulation; artificial intelligence; Movable Scaffolding System; fuzzy inference

I. INTRODUCTION

Computer simulation techniques have been widely applied in many fields. Such simulations not only predict system executions in a short time, they also reveals system operation processes during the implementation process which can improve system bottlenecks and even integrate solution-searching optimization mechanisms to improve the resource allocation planning needed to enhance productivity and competition. This technology is also gradually applied to construction operations process simulation. Therefore, this research adopts the computer simulation software Simprocess to build a set of production models according to the Movable Scaffolding System(MSS)-based bridge engineering operation (MSSBEO).The simulation reveals the process and behavior of the resource supply for the MSSBEO via dynamic simulation for efficiently predicting operation schedule, time and service rate of tools and machineries among systems. Further, previous studies in computer simulation and optimization solution search applications have not explored fuzzy inference mechanisms. If the model is too complicated or if information is insufficient or inaccurate, inaccurate parameter settings can severely affect the simulation and optimization results due to randomness. Further, it cannot consider differences traditionally resulting from subjective prejudice during decision making. Cheng [4,5], A.R. Soltani et al. [1], Zheng et al. [3], and Huang [2] proposed that the concept of fuzzy inference is led in computer simulation system and optimization search mechanism. The fuzzy inference system can fuzzify simulation output value and decrease imprecision of system data and possible faults resulting from model assumption. Therefore, this study applies the concept of fuzzy inference mechanism to a computer simulation system to model the processes of actual human decision making given subjective prejudices of each user and to reduce the simulation result errors of implementation mentioned above. Thus, the limited information acquired by managers and the environment during decision is often a multi-fuzzy objective system with subjective consciousness. The system simulation inevitably deviates from actual situations due to random and inaccurate parameter settings. Therefore, this study uses a fuzzy inference mechanism to enhance develop the MSSBEO model considering human decision-making due to system faults. This study is aimed to use the Simprocess computer simulation software to build the MSSBEO hierarchically standardized models. The dynamic simulation can predict the work schedule, cost and supply-demand behavior of resources for MSSBEO.. Incorporate a dynamic simulation model with the proposed fuzzy inference-based optimization mechanism to develop an artificial intelligence-based simulation system(Fig. 1).

< Figure 1 >

II. THE PROPOSED MSSBEO MODEL STRUCTURE

Construction Process of MSS Method

The MSS method of bridge engineering has a multi-hole continuous structure. Important considerations during construction include fresh mixed concrete pouring, allocation of post-tensioned system, estimation of pre-camber and elastic deformation, dry shrinkage and creep of mixed concrete. Figure 2 shows the bridge superstructure construction process using MSS method.

< Figure 2 >

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Introduction to the MSSBEO model structure

The section introduces the MSSBEO model structure based on Simprocess. The modeling process is the same as that described above. In addition to simulating the construction process, the model further simulates the resource supply-demand status during the construction process for subsequent analysis and use in resource combination optimization. The study subdivides the proposed model into three major sub-models based on the following operating characteristics: "Project management model", "Operating models of MSS method". The "Project Department" controls the construction interface through entities and drives each interface among "Operating models of MSS method" to start operations process; the "Operating models of MSS method" simulates operating process of superstructure and substructure in each construction interface. By starting with simulation, the model can also demonstrate resource usage and possible process bottlenecks and predict the finished status of superstructure and substructure and total construction duration and cost during simulation process.

III. Fuzzy Inference System

The mechanism of fuzzy inference is used for connecting the model and solution optimization search mechanism in the entire structure as shown in Fig. 3. Its function is to decrease the simulation result errors due to complicated and inaccurate parameters setting of the model. Meanwhile, it models subjective thinking during human decision making, tries to convert the simulation results to understandable expression ways by decision makers that further meet real situations of decision making, then applies the optimization system to find the optimal management strategy.

Through computer simulation, the proposed MSSBEO model automatically generates total cost and work schedule for the project according to parameter settings of resource cost and time, brings the generated results in fuzzy inference system to implement fuzzy inference mechanism and then lead the results after defuzzification in optimization mechanism to calculate and compare the target values. The optimization system automatically changes the resource combinations of models and repeatedly compares the simulation, fuzzy inference and target values mentioned above, until reaching Stopping Criteria. The best solution is the optimization results of resource allocation.

The fuzzy inference system consists of fuzzification interface, fuzzy knowledge base, engine of fuzzy inference and interface of defuzzification. The following description shows each part of the proposed the fuzzy inference system.

< Figure 3 >

Fuzzification Interface

Fuzzification interface is a tool for inputting data for fuzzification. After conversion by the fuzzy membership function, the data are expressed by semantic description. This study considers system architecture and actual situations. Figure 4 shows the time and cost membership function (antecedent parts of inference) set in the study.

< Figure 4 >

In Fig. 7, t3 is the limitation of work schedule entered by users and t1 is the lowest time value observed during thirty iterations of simulation. The t2 is the intermediate value between t3 and t1. The cost membership function is similarly determined. Therefore, by implementing the subjective settings of users and optimizing the search function, the membership function changes due to different resource combinations at the time of simulation as well. This corrects the disadvantages of traditional membership function mostly provided by experts, ensures that the inference procedure satisfies each case requirement, and accelerates convergence speed.

Further, it is necessary to build the corresponding membership function of projects target satisfaction after fuzzy inference procedure as shown in Fig. 5. The membership function of projects target satisfaction is defined as 0~10 grades. For example, a grade close to 10 means the decision makers are more satisfied with the project target; restated, a certain level expresses the satisfaction of decision makers with the time and cost of projects.

< Figure 5 >

Fuzzy Knowledge Base

Fuzzy knowledge base is essential for inference in the fuzzy system. The input data of the fuzzy inference system is generated directly from the simulation result. The development of fuzzy knowledge base focuses on the investigation of the work schedule and cost of output results. Due to design of fuzzy membership function, the study sets only five rules covering all possible situations. The built fuzzy rule base is shown in Fig. 6 below.

< Figure 6 >

Fuzzy Inference Engine

The proposed inference system applies the Mamdani method of fuzzy inference. The designed fuzzification interface makes the time and cost of projects belong to two semantic levels at the same time (such as "low" and "medium" or "high" and "medium"), and there is only one level left between "low" and "high". If the membership function of level "medium" is separately discussed, rules 1~4 can only contact one level during inference. The Rule 5 must necessarily be contacted. Therefore, if the rules contacted by simulation results are Rules 1 and 5, the inference is as shown in Fig. 7 below.

< Figure 7 >

Defuzzification Interface

As Fig. 8 shows, the commonly used Center of Gravity Method is applied here. The method respectively calculates the square measure and the center of A and B, leads in equation 1.1, the results are then generated from fuzzy inference are converted to clear satisfaction.

< Figure 8 >

$$Y = \frac{(Aa \times Ay) + (Ba \times By)}{Aa + Ba} \tag{1.1}$$

Y: crisp value after defuzzification

Aa、Ba: The square measure of A and B

Ay、By: The center of A and B

The Fuzzy Inference System

Using the concept of fuzzy inference system mentioned above, customized program of Simprocess software and JAVA language can develop a fuzzy inference system with the MSSBEO model. After 30 iterations of simulation, the simulation result will be accessed by the customized fuzzy inference program. Assessment of the simulation results for target satisfaction of the project indicate that the fuzzy inference results can be considered an objective optimization function.

IV. THE MODEL EXPERIMENT

Optimization Analysis

The study adopts the optimization search function, namely Opt Quest [8], attached in Simprocess to find the optimal resource allocations strategy for enhancing MSSBEO efficiency. The following sections introduce each parameter setting of optimization. This section compares the optimization results between the MSSBEO with/without the proposed fuzzy inference system. The objectives of the study were to develop optimization mechanisms with and without fuzzy inference

The Objective function with Fuzzy Inference mechanism

First, the fuzzy inference system must fuzzify the simulation results of total cost and work schedule then get crisp values after defuzzification via fuzzy inference mechanism. This crisp value expresses satisfaction with the completed schedule and cost of projects by decision makers to a certain extent. The decision maker is normally satisfied with the cost and work schedule of projects. Maximum “satisfaction” is preferred by decision makers. Thus, the objective function is to maximize the defuzzified crisp values. The system objective can be expressed as shown below.

MAX Model Defuzzification

Model Defuzzification: global attributes of crisp values for satisfaction after defuzzification.

The Objective function without Fuzzy Inference mechanism

The objective function is set by minimizing project cost controlling project completion time given the constraints. Since the model considers daily rental cost of manpower, machines and tools, when project cost is minimized, the decision maker assess whether or not the indirect cost caused by extending work schedule is worthy. The decision maker can then find an acceptable solution given the scheduling and cost requirements of the project.

MIN All Resources: Capacity Cost

All Resources: Capacity Cost: Calculated total resource cost during simulation

Selection and Settings of Decision Variable

Given the effects of cost and work schedule on system simulation, the study sets all resources to decision variable. Further, since the safety stock of each material in storage locations and procurement quantity each time may also affect inventory cost and waiting time in construction site, the study also sets them as decision variables.

Constraints

The study mainly considers constraints of in-situ construction site dimensions and transportation time of ready-mixed concrete. Thus, the study sets the limit for the inventory of each material and transportation delay of ready-mixed concrete as constraints.

Optimization Implementation Result

After setting conditions and constraints, decision variables and stop criteria, the optimization solution with fuzzy inference mechanism can search the optimal resource combinations meeting the objectives mostly in the 534th generation; the optimization solution searching without fuzzy inference mechanism can find the best solution in the 658th generation.

Analysis of simulation result using the proposed optimization model

Table 1 illustrates the results of the optimal resources combinations with/without fuzzy inference mechanism. Table 2 shows the improvement rate analysis of the work schedule and cost predicted by simulation with/without fuzzy inference mechanism. Table 3 shows the busy rate analysis of the optimal solution with fuzzy inference mechanism for resource combination compared with the original simulation without optimization can be applied.

< Table 1 >
< Table 2 >
< Table 3 >

The data in Table 3 are used to obtain the solution of the quantity of all resources after optimization with fuzzy inference mechanism has been reduced to limit setting of resources. The explanation for this phenomena is that, since resources for each operation circulate with each other, and since the supply of upstream materials is stable, the resources of each work interface are reduced to minimum are minimized] under the objective of the lowest cost. If necessary, they can support each other for the supply of materials, since the supply of upstream materials is presumably stable, the safety stock and procurement quantity are reduced to half-span.

The optimization results show that, if applying optimization introduced in fuzzy inference to implement simulation, the work schedule does not cause significant changes since the MSS method is actually a template and standard production method. Conversely, the solutions of resource combinations after optimization can largely decrease total construction cost, enhance the busy rate of each resource, and efficiently improve overstock of materials and situation of idle machines and tools since it does not affect the work schedule.

By applying the proposed optimization model, the average busy rate of resource is enhanced from the original 8.96% to 13.97%. It shows that the optimized resource combinations tend to enhance the busy status of resources (that is, minimizes the idle rate of resources. For example, consider each resource inventory for the most positive change of busy rate. Although the quantity of these resources has decreased, its relative busy rate is increased without reducing total capacity; further, the result shows that the optimized resource integration is mostly reduced to the lower limit. The exception is the 45-ton crane and operation crew of work cars, which are not reduced to the limit.

V. CONCLUSIONS AND SUGGESTIONS

1. The system developed in this study combines production process and supply-demand situation of resources and the proposed optimization model with fuzzy inference mechanism are used to implement the

simulation process and optimization. Fuzzy membership function is generated from simulation results and user settings that satisfy different requirements for each project. Through the human thinking model decision making module, the optimized decision basis can be quickly searched to further meet actual .

2. This study proposes that the fuzzy inference system should be introduced between system model and optimization module. Further, human decision making is imitated to assess optimized objectives. Fuzzy membership function, which changes according to user settings and simulation results, efficiently improves the situation in which the membership function is defined by experts and cannot satisfy the situation of different project's requirement. During the optimizing process, the membership function is also adjusted with different resource combinations in each generation and attempts to accelerate convergence rate efficiently. The most suitable resource combination after applying the proposed optimization module with fuzzy inference mechanism obtains solutions for the actual situation.
3. Selection of fuzzy membership function and inference rules and design methods affect the optimization results. The fuzzy membership function can be modified according to different requirements to strengthen the framework of fuzzy inference systems, such as by adopting the membership function of normal distribution to correct deficiencies in the triangle-shaped membership functions in reaching objectives that further meet decision maker requirements and achieve the best solution.

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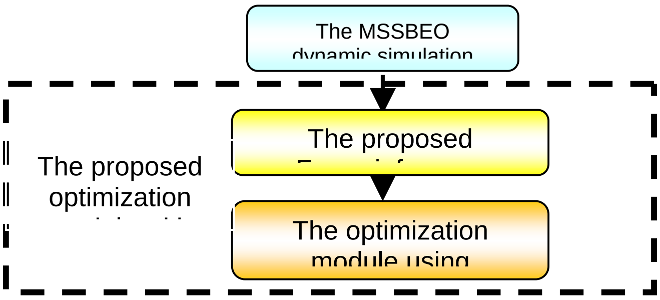


Figure 1 The MSSBEO dynamic simulation model with the proposed optimization module with Fuzzy inference mechanism

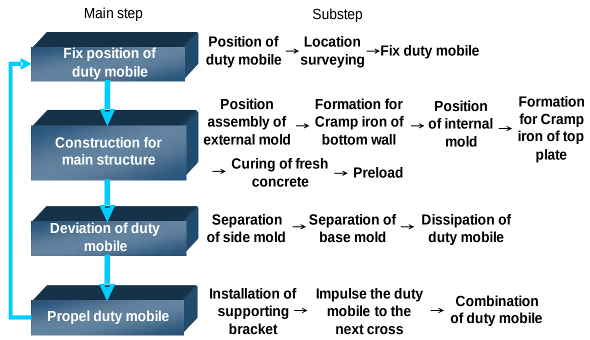


Figure 2 Construction process of MSS Construction Method

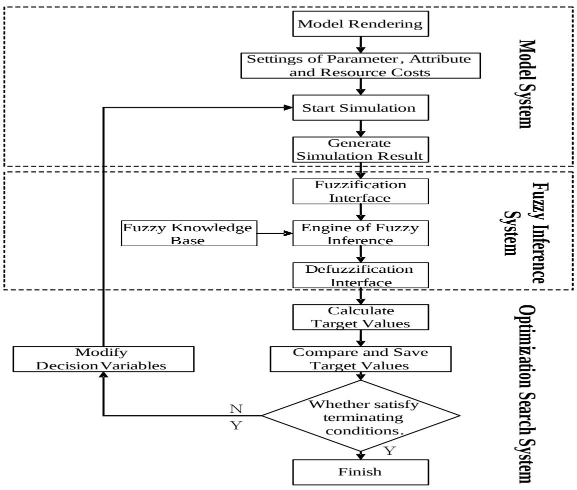


Figure 3 Framework of entire system structure

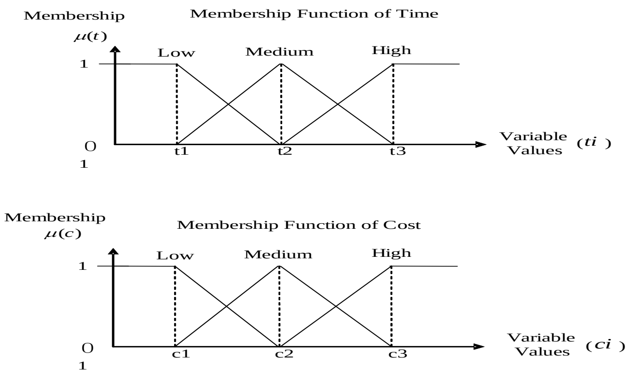


Figure 4 Time and membership function of cost fuzzification built in the study

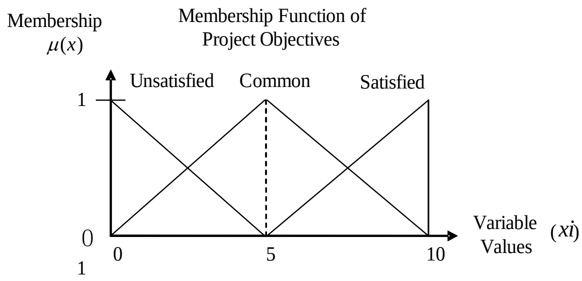
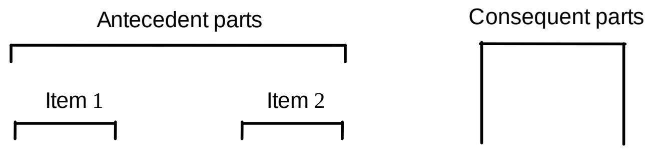


Figure 5 Target membership function of projects built in the study



Rule 1：IF time is little AND cost is low THEN the project objectives are satisfied.

Rule 2：IF time is little AND cost is high THEN the project objectives are common.

Rule 3：IF time is much AND cost is low THEN the project objectives are common.

Rule 4：IF time is much AND cost is high THEN project objectives are not satisfied.

Rule 5：IF time is medium AND cost is medium THEN project objectives are common.

Figure 6 Fuzzy rule base built in the study

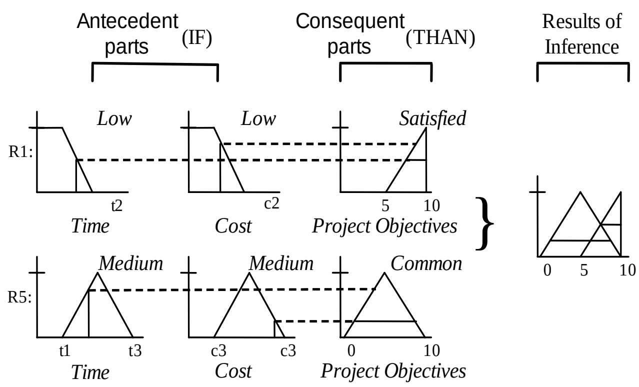


Figure 7 Fuzzy inference way built in the study

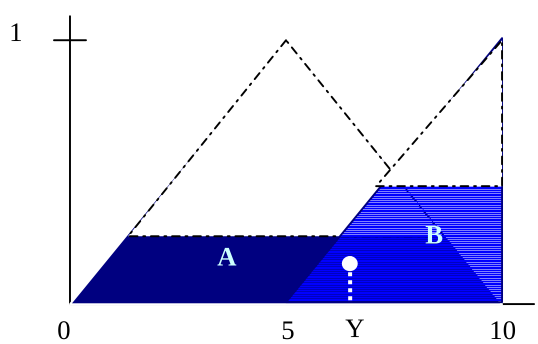


Figure 8 Framework for Center of Gravity Method of defuzzification

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< Table 1 > Searched results of optimization implementation

Optimization Settings	Introduced in Fuzzy Inference Defuzzification	Not Introduced in Fuzzy Inference Cost
Maximum Iterations	1000	1000
Automatic Stop	On	on
Objective	Maximize	Minimize
Objective Value	Defuzzification Value	All Resources：Capacity Cost
Feasible	Yes	Yes
Best Iteration	534	658
Best Objective Value	8.21501	957,870,146

< Table 2 > Variable integration after original and optimization simulation

Name of Variable	Resource Requirement Quantity of Each Work Face		
	Original Simulation	Optimization (with Fuzzy)	Optimization (without Fuzzy)
Safety Stock of Concrete	540	270	135
Safety Stock of Steel Reinforcement	132	66	33
Safety Stock of Steel Tendon	18	5	5
Procurement Quantity of Concrete	540	270	135
Procurement Quantity of Steel Reinforcement	132	66	33
Procurement Quantity of Steel Tendon	18	10	5
60-Ton Crane	2	1	1
45-Ton Crane	4	3	1
Moving concrete pump truck	5	1	1
Pallet Truck	3	1	1
Bandage crew for steel reinforcement	3	3	3
Crew for Fresh Mixed Concrete	1	1	1
Process crew of work cars	2	3	2
Crew of prestress	1	1	1

< Table 3 > Improving Status after applying the optimization resource

Name	Unit	Original Simulation 30 Average	Optimization (with fuzzy) 30 Average	Improvement Rate
Number of Total Constructions	Day	631.9244	630.8058	0.18%
Total Cost	NT$	About 1.36955 billion	About 1.12305 billion	17% (About 0.25 billion)
Name	Unit	Original Simulation 30 Average	Optimization (without fuzzy) 30 Average	Improvement Rate
Number of Total Constructions	Day	631.9244	632.2086	-0.04%
Total Cost	NT$	About 1.36955 billion	About 0.95787 billion	30% (About 0.41 billion)

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