

Evaluating Service System Alternatives via a Computer Simulation-enabled MCDM Framework

Wei-Jaw Deng¹, Wen Pei¹ and Chih-Hung Tsai^{2†}

¹Graduate School of Business Administration
Chung-Hua University
No. 707, Sec. 2, Wu Fu Road, Hsin-Chu 30012, Taiwan

²Department of Industrial Engineering and Management
Ta-Hwa Institute of Technology
1 Ta-Hwa Road, Chung-Lin, Hsin-Chu, Taiwan, ROC
Tel: +886-3-5927700-2953
E-mail: ietch@thit.edu.tw

Abstract

Decision makers in the service industry must effectively cope with queuing problems, service capacity optimization, service efficiency and service quality problems. This study proposes a computer simulation-enabled MCDM framework that integrates computer simulation analysis, Taguchi method, expert opinion and multiple criteria decision making (MCDM) to assist decision makers in coping with decision problems. In this framework, Taguchi method is adopted to reduce the time required for the simulation experiment. Computer simulation analysis is adopted to obtain useful information for rapid decision-making without interrupting actual production. MCDM is used to select the optimal alternative. The illustrative result is extremely promising.

Key Words: Computer Simulation, Taguchi Method, Expert Opinion, MCDM, Service Industry

1. Introduction

In operation management, decision makers often use experience based judgment or trial and error to handle operating problems and make decisions regarding the manufacturing or service industry. Owing to the complexity of the system problem and the numerous performance evaluation criteria in the current operating environment, the use of experience based judgment or trial and error in operation management may be associated with a higher decision risk. Decision makers have difficulty in obtaining sufficient information for reference in decision making under certain constraints, including time, cost, individual intelligence, and so

†Corresponding Author

on. Therefore, the correct evaluation of the impact of each performance criterion and the correct evaluation of the total system performance effectiveness are two key issues for decision makers to consider when using the multiple criteria decision making (MCDM) method to select optimal alternatives for resolving business process problems (Tsauro *et al.*, 2002).

Computer simulation can rapidly provide decision makers with valuable information for selecting suitable and rational alternative solutions to problems no matter decision maker deals with, whether for existing or non-existing system problems (Saunders *et al.*, 1989; Andreatta *et al.*, 2007). For simplification consideration, most problem analysis uses a single objective criterion to evaluate the performance of alternatives when applying computer simulation [4]. However, problem analyzers neglect that the optimal solution can not be valid when considering only one single objective criterion. Therefore, problem analyzers should apply the concept of multiple objective criteria evaluation when performing simulation analysis (Tsauro *et al.*, 2002). The MCDM technique has been applied extensively to decision analysis and performance evaluation (Hwang and Yoon, 1981; Yoon and Hwang, 1995). However, these two methods, computer simulation and MCDM, are generally used separately and can not exert both methods' efficiency on decision analysis works. Consequently, this study examines how to combine computer simulation with MCDM to provide decision makers with such analysis methods to select the optimal alternatives for rapidly and objectively solving the problem.

The effectiveness of service system design, service process flow design and the management of service production depend on making correct management decisions in the service industry domain (Zapf, 2004). Decision makers involved in managing business operations face challenging problems of queuing, capacity optimization, service efficiency and service quality problems (Sheu *et al.*, 2003). Under this situation, the most competitive group will be the one that can grasp the present situation, analyze the problem, make right decision and implement solution alternative rapidly. This study attempts to provide a computer simulation-enabled MCDM framework which can be used by service industry decision makers to acquire useful information and efficiently reach an excellent decision.

This computer simulation-enabled MCDM framework integrates computer simulation analysis, the Taguchi method, expert opinion and MCDM. Within this framework, Taguchi method is used to reduce the time required for simulation experiments. Computer simulation analysis is applied to derive useful information for rapid decision making without interrupting actual production. Expert opinion is used to assign preference weightings to multiple criteria. Moreover, MCDM is used to select the optimal alternative. Additionally, a Multiple Criteria Decision Making Support Programming (MCDMSP) which applies Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) technique was created to help decision makers rapidly and easily identify the optimal alternative. An assumptive VCD/DVD rental shop provides an implementation example to illustrate the implementation of the framework and its possible effectiveness. Based on the assumptive VCD/DVD rental shop implement-

ation results, this computer simulation-enabled MCDM framework can help service industry decision makers rapidly solve management problems or make decisions while minimizing risk in the present dynamic and competitive market.

2. Computer Simulation-enabled MCDM Framework

The computer simulation-enabled MCDM framework, which integrates computer simulation, the Taguchi method, expert opinion and MCDM technique, comprises seven steps:

- Step 1: Identify the appropriate criteria for evaluating alternatives in service process performance.
- Step 2: Determine the reasonable preference weights of multiple criterion based on expert opinion.
- Step 3: Build a verified and validated computer simulation model of the subject service system.
- Step 4: Plan simulation experiment execution, including reasonable run length and replication number.
- Step 5: Arrange the simulation experiment using Taguchi orthogonal array to achieve the benefit of fewer experiments.
- Step 6: Develop Multiple Criteria Decision Making Support Programming (MCDMSP) which applies TOPSIS techniques.
- Step 7: Run computer simulation first followed by MCDMSP to rank different alternatives.

The executive approaches are presented in detail in the following sections.

2.1 Identify the Appropriate Performance Evaluation Criteria

The superior or inferior performance results for service process depend on the performance of the specific object criteria. In MCDM, analyzers completed the performance evaluation by evaluating the performances of overall multiple criteria. The popular performance evaluation criteria generally derive from previous research on service industry performance evaluation. Table 1 lists the performance evaluation criteria typically used for service systems.

“Total service customer number (TSCN)” is the easiest criterion of multiple performance evaluation criteria for understanding service system performance. TSCN resembles a product number in manufacturing, with higher TSCN indicating that more sales have been made. “Average customer waiting time (ACWT)” criterion is widely used in numerous computer simulation analyses for the service industry (Klassen and Rohleder, 1996; Swisher *et al.*, 2001; Zhao *et al.*, 2002). This criterion means the same as

Table 1. The criteria for performance evaluation

Category	Criterion	Quoted article
Flow time	1. Average service flow time for serving a customer 2. Total service customer number	Chung and Sodeinde, (2000), Sheu <i>et al.</i> (2003), Juran and Schruben, 2004; Kharwat, (1991), Klassen and Rohleder, (1996), Ohboshi <i>et al.</i> (1998), Pagell and Melnyk, (2004), Sheu and Babbar, (1996).
Waiting time	1. Average customer waiting time 2. Average waiting customer number in waiting line	Chung and Sodeinde, (2000) Zapf, (2004), Sheu <i>et al.</i> (2003), Ohboshi <i>et al.</i> (1998), Sheu and Babbar, (1996), Kim and Kim, (2001), Lam and Lau, (2004), Swisher <i>et al.</i> (2001), Zhao <i>et al.</i> (2002).
Utilization	1. Average service personnel utilization rate 2. Average service personnel idle rate	Zapf, (2004), Ohboshi <i>et al.</i> (1998), Chen and Kuo, (2000).

average number of customers waiting in line. Low ACWT creates a perception among customers of better service quality. "Average service personnel idle rate (ASPIR)" is an important criterion involved in productivity management since manpower resources represent a substantial proportion of total business operating costs and also influence service system performance. Consequently, total service customer number, average customer waiting time and average service personnel idle rate are suitable criteria for evaluating service performance. As shown in Table 1, these three criteria have also been applied by numerous service industry analysts in their research.

2.2 Determine the Reasonable Preference Weights of Criteria

Since good decisions require the consideration of multiple criteria, decision makers must determine reasonable preference weights for multiple criteria to evaluate the performance of service process alternatives. When analysts use the expert opinion method to determine the criterion weight, the critical factor is creating a suitable panel of experts. Such a suitable panel of experts should include the relevant authorities, corporations and academic experts with relevant knowledge and experience (Chan *et al.*, 2001). After surveying these experts, information regarding the criteria weighting is gathered and the average weight of each criterion is calculated. The average criteria weights can then be used in the MCDM procedure.

2.3 Build a Verified and Validated Computer Simulation Model

Unlike manufacturing systems, service industry systems are extremely labor-intensive. Moreover, demand for such systems is generally intermittent and not uniform. Computer simulation plays a key role in solving complex operational problems and enhancing both productivity and efficiency (Kharwat, 1991; Lin *et al.*, 2000). Computer simulation provides an

accurate way to evaluate changes in the objective system without disturbing normal daily operations (Kelton *et al.*, 1998). The computer simulation system has a strategic impact on positioning service systems to operate more efficiently, since analysts generally use computer simulation for the following tasks: detecting system bottlenecks, verifying operating standards, determining peak performance equipment capacities, determining peak hour capacity requirements, determining customer service times during peak and non-peak times and answering “what if” questions (Kharwat, 1991; Swisher *et al.*, 2001).

The simulation analysts can build the objective computer simulation model with reference to the modeling approach presented in simulation theory books, such as “Simulation Modeling and Analysis” (Law and Kelton, 2002). The simulation analysts also need to decide what simulation package software they will apply. Computer simulation analysts can apply numerous simulation package software, including ARENA, ProModel, AutoMod, WITNESS, SIMFACTORY, and so on, to perform computer simulation analysis. The verification and validation of objective computer simulation model is the most important approach in computer simulation development. Verification ensures that the conceptual model is consistent with the computer simulation model. Meanwhile, validation ensures that the computer simulation model matches real system (Proctor, 1996). Debug and Sensitivity Analysis are generally utilized to complete these two jobs.

2.4 Execution Planning for the Simulation Experiment

After the simulation analyst completes the verification and validation of the computer simulation model, they can use this computer simulation model to gather performance data on the focal service process alternative. The simulation analyst executes a simulation run for each possible service process alternative to gather performance data. Because the service system is a terminating system, the number of runs and run length are the two determining factors for the simulation experiment (Law *et al.*, 2002). The run length for each simulation equals the total service system operating time. Statistical methods can be applied to determine a suitable number of runs. The formula for determining the suitable number of runs is listed as follows:

$$d = Z_{\alpha/2} \frac{\sigma}{\sqrt{n}} \longrightarrow n = \frac{Z_{\alpha/2}^2 \sigma^2}{d^2} \quad (1)$$

where d = the specified tolerance, σ = the standard deviation of the performance criterion and $Z_{\alpha/2} \frac{\sigma}{\sqrt{n}}$ the half-length of the $(1-\alpha)100\%$ confidence interval. The details for determining the suitable number of runs can be found in (Law and Kelton, 2002).

2.5 Arrange Simulation Experiment

If the number and the level of control parameters significantly influenced the system performance are too many, then the total number of simulation experiments will increase markedly. Currently, analysts generally apply Taguchi orthogonal array to arrange simulation experiments and thus reduce the total number of experiments (Chen and Hsiao, 2001). The Taguchi orthogonal array approach for arranging experiments involves: determining the number and level of control parameters; calculating total experimental freedom; selecting a suitable Taguchi orthogonal array with sufficient degree of freedom for arranging all control parameters; modifying the line-dot diagram and arranging the control parameters into each dot position. Subsequently, analysts can execute computer simulation experiments based on the control parameter combination setting of each row in the target Taguchi orthogonal array (Roy, 2001).

2.6 Develop the MCDMSP

In the current conflict management environment, decision makers frequently use MCDM to rank alternatives and select the optimal alternative. Hwang and Yoon (Hwang and Yoon, 1981) developed TOPSIS to assess alternatives during multiple criteria decision making. TOPSIS is a widely accepted multiple criteria decision making technique due to its sound logic, simultaneous consideration of both ideal and the negative ideal solutions, and easily programmable computation procedure (Kim and Kim, 2001). The ideal solution is that which maximizes the benefit criteria and minimizes the cost criteria, while the negative ideal solution is that which maximizes the cost criteria and minimizes the benefit criteria. Furthermore, the optimal alternative is that which is closest to the ideal solution and farthest from the negative ideal solution. TOPSIS ranks alternatives based on the criterion "the relative similarity to the ideal solution". It avoids the situation of identical similarity to both the ideal and negative ideal solutions (Tsaour *et al.*, 2002; Opricovic and Tzeng, 2004). The procedure of TOPSIS is described in the references (Tsaour *et al.*, 2002; Hwang and Yoon, 1981; Yoon and Hwang, 1995; Tong *et al.*, 2004).

Decision makers can develop a Multiple Criteria Decision Making Support Programming (MCDMSP), which applies the TOPSIS technique using any familiar programming language. MCDMSP can be integrated into computer simulation via simulation output export function and batch-run function in certain simulation software packages. Consequently, analysts can run the computer simulation and simultaneously complete MCDMSP to rapidly and easily obtain the ranking of service process alternatives.

3. Illustrative Example

To illustrate the computer simulation-enabled MCDM framework, an assumptive VCD/

DVD rental shop service system is proposed. The service system design resembles a real VCD/DVD rental shop. Only the process parameters and their levels are assumptive.

3.1 Identify the Appropriate Performance Evaluation Criteria

Based on the description in the 2.1 subsection, this illustrative example uses “total service customer number,” “average customer waiting time” and “average service personnel idle rate” to evaluate the different alternatives performed in the service system.

3.2 Determine the Reasonable Preference Weights of Criteria

Reasonable criteria preference weights were determined based on expert opinion. Following interviewing ten VCD/DVD rental shop managers, the average weights for each performance evaluation criterion used in this illustrative example were listed in Table 2.

Table 2. The average weight of performance evaluation criterion

Criterion	TSCN	ACWT	ASPIR
Average Weight	0.33	0.43	0.24

3.3 Build a Verified and Validated Computer Simulation Model

In the assumptive VCD/DVD rental shop service system, customers enter a VCD/DVD rental shop, select a VCD/DVD, maybe buy some snacks as well, pay for what they have selected and leave the shop. However, according to the building simulation model approach proposed in the book “Simulation Modeling and Analysis” (Law and Kelton, 2002), the computer simulation analysis model for assumptive VCD/DVD rental shop has been created using the high-level simulator ARENA, which is based on the SIMAN simulation language (Kelton *et al.*, 1998; Rockwell Software Inc, 2002). Figure 1 shows the computer simulation model.

All setting values of control parameters in the computer simulation analysis model are assumptive. For example, the arrival rate is modeled as a stochastic Exponential-distribution with parameter $\lambda=8\text{min}$. Moreover, customers selected equal percentages of different kinds of VCD/DVD. The time required for selecting VCD/DVD is modeled as a Triangular-distribution with parameters (min = 1, mode = 5, max = 10). Moreover, 25 percent of customers buy snacks. The time required for selecting snacks is modeled as a Triangular-distribution with parameters (min = 2, mode = 4, max = 6). Moreover, the time required for checking out is modeled as a Triangular-distribution with parameters (min = 1, mode = 3, max = 4). The operating time is from 11AM to 11PM. Following model debugging and sensitivity analysis, the illustrative VCD/DVD computer simulation model possesses the characteristics of verification

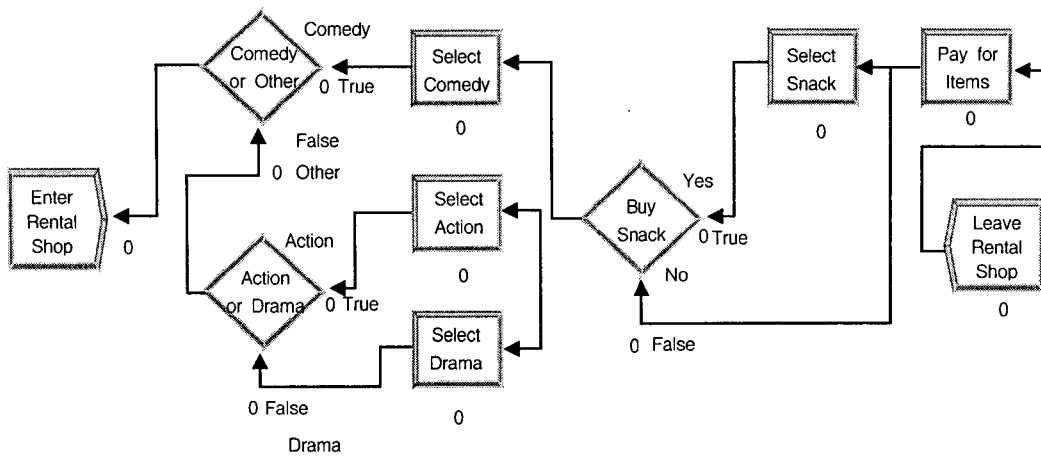


Figure 1. VCD/DVD rental shop ARENA simulation model

and validation. In practice, analysts must first obtain real operating data and then determine the value of each control parameter.

3.4 Execution Planning for the Simulation Experiment

Since VCD/DVD rental shop is a terminating system, the simulation run length is the operating time of the shop, which is 720 minutes (from 11 AM to 11 PM). The suitable number of runs can be obtained using formula (1), in which the estimation error is less than 3 percent and the level of significance (α) is 5 percent. Following 30 pilot runs, the standard deviation of ACWT is 0.21 minutes. Consequently, the suitable number of runs calculated by formula (1) is almost 110.

3.5 Arrange Simulation Experiment

By applying the Taguchi orthogonal array to arrange experiments of the illustrative example, the first task is the determination of the number and level of control parameters. For simplicity, the level is set to two for all control parameters. The control parameters that exert the main influence on the performance of this illustrative example are customer entry time, VCD/DVD select time, snack select time and checkout service time. The setting values for all influential control parameters are assumptive. Table 3 lists the details.

Since there are four factors, each with two levels, the experiment has a total of four degrees of freedom. Consequently, the $L_8(2^7)$ Taguchi orthogonal array is suitable for this experiment. The four influential control parameters are arranged into first four columns and the rest of the columns are arranged to error factor. Table 4 lists the assignment $L_8(2^7)$ result

Table 3. The influence control parameters for performance

Number	The influence control parameter	Level 1	Level 2
A	customer entry time	Expo(4)	Expo(8)
B	VCD/DVD select time	Triangular(1, 5, 10)	Triangular(3, 7, 12)
C	snack select time	Triangular(2, 4, 6)	Triangular(3, 5, 7)
D	checkout service time	Triangular(1, 3, 4)	Triangular(2, 4, 5)

Table 4. $L_8(2^7)$ Orthogonal array

Column	1	2	3	4	5	6	7
Factor Assign	A	B	C	D	e	e	e
1 (original A)	1	1	1	1	1	1	1
2 (Alternative B)	1	1	1	2	2	2	2
3 (Alternative C)	1	2	2	1	1	2	2
4 (Alternative D)	1	2	2	2	2	1	1
5 (Alternative E)	2	1	2	1	2	1	2
6 (Alternative F)	2	1	2	2	1	2	1
7 (Alternative G)	2	2	1	1	2	2	1
8 (Alternative H)	2	2	1	2	1	1	2

of four influential control parameters and three error factors. Each row in the Taguchi orthogonal array represents an alternative that VCD/DVD rental shop can use to improve system performance. A total of eight alternatives exist. The first alternative is the original operation condition and the remainders are alternatives that shop managers can select and implement to improve system performance.

3.6 Develop the MCDMSP

This study uses the Visual Basic programming language to develop a Multiple Criteria Decision Making Support Programming (MCDMSP) which applies the TOPSIS technique. The MCDMSP involves two setting processes. One process is the setting of service process alternative number and performance criteria number, while the other is the setting of the performance criteria weights. By using the output export function and batch-run function in the ARENA software package, the analyst can run the computer simulation and simultaneously complete MCDMSP to rapidly and easily derive the ranking result of service process alternatives. The service process alternative number and performance criteria number setting window of MCDMSP is shown in Figure 2.

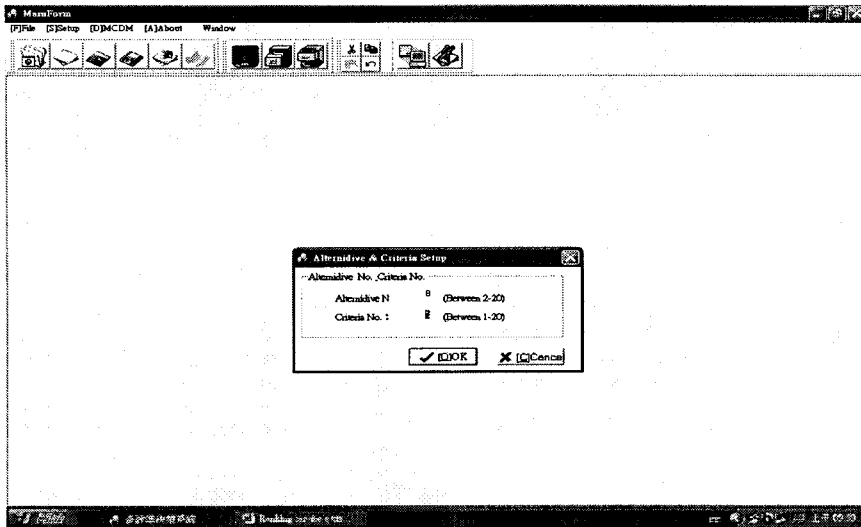


Figure 2. Service process alternative number and performance criteria number setting window of MCDMSP

4. Numerical Results

4.1 Multiple Criteria Decision Result

The numerical implementation uses three performance evaluation criteria, specifically “total service customer number,” “average customer waiting time” and “average service personnel idle rate” to evaluate the performance of alternative service processes. This study ran eight

Table 5. Performance value of three evaluation criterion

Alternative \ Criterion	TSCN (larger is better)	ACWT (less is better)	ASPIR (less is better)
A	177.53	2.76	0.3421
B	179.04	21.43	0.0877
C	177.79	2.67	0.3415
D	180.96	22.55	0.0802
E	89.71	0.689	0.667
F	88.89	1.642	0.547
G	90.38	0.683	0.666
H	89.35	1.492	0.545

experiments. Each experiment involved a factor level combination of four parameters, namely “customer entry time,” “VCD/DVD select time,” “snack select time,” and “checkout service time”. In each experiment, four influential performance parameters were set in different levels. Each experiment presented a different service process alternative for a VCD/DVD rental shop. The detailed performance results for each service process alternative experiment are listed in Table 5, and the service process alternative ranking result derived from MCDMSP is listed in Table 6.

Table 6. Ranking of eight alternatives by MCDM

Ranking	1	2	3	4	5	6	7	8
Alternative	G	E	H	C	F	A	B	D

4.2 Single Criterion Decision Result

Decision makers generally use single criterion decision analysis to select optimal service process alternatives for the sake of simplicity. This study finds it is possible to rank eight alternatives differently under different single performance criterion. The ranking results of eight alternatives based on different single performance criterion are listed in the following three tables, from Table 7 to Table 9.

Table 7. Ranking of eight alternatives by TSCN

Ranking	1	2	3	4	5	6	7	8
Alternative	D	B	C	A	G	E	H	F

Table 8. Ranking of eight alternatives by ACWT

Ranking	1	2	3	4	5	6	7	8
Alternative	G	E	H	F	C	A	B	D

Table 9. Ranking of eight alternatives by ASPIR

Ranking	1	2	3	4	5	6	7	8
Alternative	D	B	C	A	H	F	G	E

4.3 Comparison

Based on the results listed in Tables 6 to 9, the optimal service process alternative is G

alternative when decision makers use the MCDM approach. In this situation, the service process system can achieve higher performance when all performance criteria are considered. If decision makers use the single criterion decision making approach, the optimal service process alternative is D alternative, when total service customer number or average service personnel idle rate is the only performance evaluation criterion. However, the optimal service process alternative is also G alternative when average customer waiting time is the only performance evaluation criterion. Even the optimal service process alternative, G alternative, is same both derived from MCDM and ACWT in this illustrative example. But this did not mean that the fact is always true in others situations. Moreover, in the single criterion decision making approach, the optimal service process alternative is determined based on just one performance criterion. The overall system performance of optimal service process alternative may be inferior to optimal service process alternative derived from MCDM. Therefore, analysts that use a single criterion decision making approach to select optimal service process alternative may suffer higher decision risk.

From the perspective of experiment number, the computer simulation-enabled MCDM framework required a total of eight runs, which was half that required for the general computer simulation experiment (complete factor experiment had four parameters with two levels; number of experiment is sixteen). The implementation of proposed computer simulation-enabled MCDM framework can reduce total decision making costs. Furthermore, the MCDMSP integrated with computer simulation can rapidly rank the service process alternatives and provide reference information for analysts to select the optimal service process alternatives.

5. Conclusions

In the current highly competitive business market, performance evaluation is crucial in maintaining competitive competence, whether in manufacturing or service industry management. Performance evaluation is a complex task. Analysts must put considerable effort into performance evaluation to achieve well timed, precise, and effective results. Computer simulation can assist decision maker in obtaining useful information for selecting suitable alternative solutions to problems with or without the existence of a system problem. MCDM can assist decision makers in ranking problem solution alternatives in situations involving multiple criteria. The proposed computer simulation-enabled MCDM framework can provide effective assistance to service system decision makers in coping with problems involving queuing, service capacity, service efficiency, and service quality. Based on the results of the illustrative examples, the number of experiments reduces by 50 percent when the proposed computer simulation-enabled MCDM framework is implemented. Furthermore, the continuous operation of computer simulation process and MCDM process also reduce the high levels of

analysis and decision risk that generally existed in the single criterion decision making. Service system decision makers can refer to the proposed computer simulation-enabled MCDM framework as a basis for building their own business system computer simulation model and MCDMSP. These models can be used in the future time to rapidly resolve problems resulting from the dynamic and competitive business market.

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