ICIC Express Letters ICIC International ©2022 ISSN 1881-803X
Volume **16**, Number **6**, June **2022** pp. **605–612**

SOCIAL-WELFARE-ENHANCING FRAMEWORK CONSIDERING INDIVIDUAL PREFERENCES IN THEME PARK PROBLEM

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Received October 2021; accepted December 2021

Abstract. *The theme park problem is a kind of resource allocation problem. The goal of this type of problem is to improve a social system composed of individuals. Some methods have been proposed for reducing a traveling time. However, there are few methods for directly increasing social utility in theme parks. In a real theme park, individual utilities of visitors are usually different from each other. In this paper, we propose a method to enhance social welfare considering individual preferences. In the proposed method, each user determines his/her own preferences which represent priority of individual utilities. This framework guarantees visitors' individual optimalities in the meaning of maximizing total personal utility and it has a potential to enhance the social welfare. Computer experiments show that the proposed method causes better results.*
Keywords: Theme park problem, Resource allocation problem, Mass user support, Statement-based cost estimate, Individual preference, Multiagent system

1. **Introduction.** Socially shared service facilities are inseparable from people's lifestyle. The service facilities, in this paper, mean "first-come-first-service" facilities for any demands. The examples of these facilities include attractions in a theme park and roads in a traffic system. Over-capacity users in these facilities make a bad effect to other users and services, because they make a long queue.

Mass user support is proposed to solve dynamic resource allocation problems [1]. This concept is not only to optimize individuals but also to adjust a social system. The theme park problem is proposed as a benchmark of mass user support and multinomial model is developed [2,3]. Statement-based Cost Estimate (SCE) that considers future congestions is proposed as an approach to mass user support systems [4]. SCE is a framework to guarantee the individual optimality, which means to minimize the individual travel time which is the difference between the departing time from an origination and the arrival time to a destination and reduce the total travel time of all users. In other research, Pareto optimal plans and Statement-based Cost Estimate (P-SCE) that is based on SCE is proposed [5]. P-SCE succeeded in reducing the total travel time to ease the definition of the individual optimality from to minimize the individual travel time to Pareto optimality. Pareto optimality means that user cannot choose only one plan when there are more than two Pareto plans.

In these researches, social welfare is regarded as only a travel time. However, from user's perspective, there are other elements of social welfare, such as a moving time and a waiting time. Which elements are important is also different for each user. In optimal travel routes problem, significant values of utility functions are extracted from analysis of hierarchy process [6].

DOI: 10.24507/icicel.16.06.605

In this paper, we show the framework to enhance social welfare, considering individual preferences. Our framework guarantees the individual optimality, to maximize individual utility. Only thinking of the travel time as the individual optimality is equal to that the individual utility is just the travel time. Therefore, our method is the more general and practical framework.

This paper is organized as follows. Section 2 describes the previous work of the theme park problem, especially SCE, and defines the theme park problem. In Section 3, we explain the user planning and our proposed framework. Section 4 shows some experimental results and we discuss them. Finally, Section 5 concludes our paper, and discusses future work.

2. **Theme Park Problem.** The theme park problem is an example of mass user support research area. The objective of the theme park problem is to develop an algorithm that coordinates the visitor's behavior to increase social utility. Because visitors' activities make an effect on each other, a theme park is a dynamic resource allocation problem and to optimize social system is very difficult for its huge solution space. Theme park problem is represented a multiagent model and can be extended to another more complex resource allocation problem that is described by multiagent systems by introducing some constraints.

2.1. **Environment.** A theme park consists of service facilities that are attractions, roads, an origination and a destination. The service facility, which provides users its service under first-come-first-service rule, is represented as a node. Nodes are connected by directed edges, which show the possible transition relationship between nodes, and these nodes and edges constitute a directed graph network. Node v_i has two given static parameters and dynamic one. The static ones are the service time st_i, capacity c_i, and dynamic one is $queue_i$. Node $v_i \in \{v_1, v_2, \ldots, v_M\}$ can serve the number of c_i users simultaneously. Visitors can receive each service immediately when arriving at node v_i if the number of users receiving service at a node is less than its capacity c_i, and user needs to spend the service time st_i to pass to a next node. On the other hand, over-capacity users, who enter a node that serves full of its capacity, must wait that prior users finish receiving service. Over-capacity users make a queue and join it to wait for their turn, and the number of users queuing up on node v_i is denoted by $queue_i$. Capacity c_i is usually set to a finite number, but can be set to an infinite number. Infinite c_i describes that all users can receive its immediate service at any time and node v_i has no $queue_i$.

We suppose a discrete multiagent theme park model. User $a_j \in \{a_1, a_2, \ldots, a_N\}$ enters the theme park at each time t according to the Poisson distribution with arrival rate of the Poisson distribution λ. After each user a_j departs v_1, the origination node, goes toward v_M, the destination node, through some facilities. User a_j respectively has some nodes which user has to visit at least once until arriving at the destination node. This is one example of constraints in the theme park problem. Users continue to enter the theme park until the number of users reaches the maximum number N. Individually objective of user is to get the $plan_j = \left\{node_j^1, node_j^2, \ldots, v_M\right\}$ to maximize his/her own utility. User's plan $plan_j$ consists of a sequence of nodes the user intends to visit and show the node the user should go to next. Also, $node_j^k$ denotes the node the user a_j intends to visit k-th in $plan_j$.

User a_j calculates his/her own utility u_j according to the result as a series of user's behavior when arriving at the destination node. The social welfare U is defined as follows:

$$U = \sum_j u_j, \tag{1}$$

where u_j represents the individual utility of a_j, and u_j is composed of several utility functions. Therefore, if there are K utility functions, these are denoted as u_{jk} ($k =$

$0, 1, \ldots, K$). How to calculate individual u_j using u_{jk} is main part of this paper and described in Section 3. To maximize U is the most important issue in the theme park problem. Estimation of uncertain future situations is a key to resolve an optimization problem of a social system.

2.2. **Statement-based Cost Estimate (SCE).** Statement-based Cost Estimate (SCE) is a promising approach of mass user support [4]. SCE is composed of planning and cost estimation and repeats this process at regular intervals. This process makes future estimation accurate. For future estimation, "statements" is introduced as a new dynamic parameter of users which represents a potential timing each user arrives a node in plan by SCE. When user decides his/her own plan, $plan_j$ is fixed, $node_j^k$ and $time_j^k$ that is the time user a_j intends to visit $node_j^k$ are also fixed.

$$statement_j(v_i, t) = \begin{cases} 1 & \exists k, v_i = node_j^k,\ t = time_j^k, \\ 0 & \text{otherwise.} \end{cases} \tag{2}$$

In other words, $statement_j(v_i, t)$ takes 1 if user a_j intends to arrive $node_j^k$ at the time t, otherwise, it takes 0. Our method is based on SCE; therefore, we describe its way to estimate the cost.

As a premise, a central system of the theme park has the information of the set of statements. Moreover, this information of statements is available for user a_j with a mobile device, such as a mobile phone, and user has to send his/her own $statement_j(v_i, t)$ if user a_j uses SCE. First, the number of potential users who intend to join the queue at node v_i from a current time t_c to a future time t_f is defined.

$$num_i^*(t_f) = queue_i(t_c) + \sum_{t=t_c}^{t_f} \sum_j statement_j\left(v_i, t\right). \tag{3}$$

SCE supposes that the number of $num_i^*(t_f)$ users waits in the prior queue at node v_i when user a_j arrives at node v_i. Because node v_i continuously gives its own service until user a_j arrives at v_i, the estimated queue list at node v_i is defined as follows:

$$queue_i^*(t_f) = \max\left[0, num_i^*(t_f) - \lfloor (t_f - t_c) \cdot (c_i/st_i) \rfloor\right]. \tag{4}$$

The $cost_i^*(t_f)$ which represents the required time to pass node v_i at the current or future time t_f is defined using the estimated queue length in Equation (4).

$$cost_i^*(t_f) = \lfloor queue_i^*(t_f)/c_i + 1 \rfloor \cdot st_i + 1, \quad t_f > t_c. \tag{5}$$

Especially, at t_c, the state of user a_j is either receiving the service at node v_i or on the queue list at node v_i to wait its turn. The $cost_i^*(t_f)$ in such a case is defined as follows:

$$cost_i^*(t_f) = \begin{cases} remaining\_time_j & \text{if } a_j \text{ is in service,} \\ \lfloor pqueue_i(t_f)/c_i + 1 \rfloor \cdot st_i + 1 & \text{otherwise,} \end{cases} \quad t_f = t_c, \tag{6}$$

where $pqueue_i$ represents the number of prior queuing users against user a_j in the queue list of node v_i. In the case capacity c_i is the infinite number, the cost is equivalent to $st_i + 1$.

Estimated $time_j^k$ is defined using above Equations (2)-(6).

$$\begin{cases} time_j^k = t_c, & k = 1, \\ time_j^k = time_j^{k-1} + cost^*_{\left(node_j^k\right)}\left(time_j^{k-1}\right) & k \geq 2. \end{cases} \tag{7}$$

In the research related to SCE, the evaluation of framework in the theme park problem is the travel time. This means that last $time_j^k$ in Equation (7) is equivalent to the estimated utility. Therefore, SCE is the planning algorithm to minimize last $time_j^k$.

3. **Proposed Method.** We proposed a framework which optimizes a social system, considering individual preferences. In the theme park, there are several measures of utility and visitors' ones differ from each other. In the previous studies, related to SCE and P-SCE, the number of utility functions K is one and three respectively, and their main objectives are to minimize the average travel time in the theme park. Although the result of SCE shows that it achieves this objective, it cannot consider utilities other than the travel time because the utility function is equivalent to the travel time. In P-SCE, there are three utility functions to make Pareto optimal plans; however, considering with each preference is not enough because Pareto optimality exists under the condition that all utilities are evaluated equally. Moreover, the additional utilities are not considered in evaluating the social utility.

3.1. **User planning.** Our proposed method is based on SCE framework. The planning of each user is carried out at the timing entering an origination. After first planning, user a_j plans every interval $interval_j$. SCE uses estimated travel time tt_j^* for the evaluation of planning $plan_j$ for user a_j. Estimated waiting time wt_j^* and moving time mt_j^* can be also estimated for using SCE framework and P-SCE uses these values. Our proposed method also uses these values. Travel time tt_j of user a_j is the difference between the departure time from an origination and the arrival time to a destination. Next, waiting time wt_j is the total time composed of each time when user a_j waits in each queue list. Finally, moving time mt_j is equivalent to the sum of service times st_i in case that service capacity c_i is set to the infinite number. In the process of calculating waiting time, maximum waiting time $wt_j^{\max}$ and minimum waiting time $wt_j^{\min}$ are calculated. Of course, these estimated values, $wt_j^{*\max}$ and $wt_j^{*\min}$ can be also calculated.

For user planning, a simple local search and Dijkstra's algorithm are available [7]. First, an initial plan is decided as a random order of not-visited attraction nodes from four individually given nodes which user has to visit once. Next step of the planning, Dijkstra's algorithm makes a shortest path from a current node to a destination node through not-visited nodes following the order in the initial plan. This plan is kept as the first candidate plan and individual utility u_j^* is estimated. How to estimate u_j^* is described later. After planning a candidate plan, a neighbor plan is generated by changing an order of random two attractions in the candidate plan. The neighbor plan is evaluated as the comparison with current candidate plan, and replaced if the neighbor plan excels the candidate one. This process between generating neighbor plan and replacing is repeated until the replacement does not occur for 15 times. The final candidate plan is decided as a formal plan.

3.2. **Weighted-utility and Statement-based Cost Estimate (W-SCE).** For considering the difference in individual utility u_j, we suppose preferences p_{jk} which represent the importance of several utility functions u_{jk} for each user. There are many types of user in a real theme park, a family with a child, an old person, or a person with leg injury. For example, a person with leg injury puts emphasis on a moving time. The p_{jk} exist as many as u_{jk}, and a larger p_{jk} means that the corresponding utility u_{jk} is more important; when p_{jk} is zero, user a_j disregards u_{jk}. Preferences p_{jk} are defined randomly for each user, and the individual sum of p_{jk} is equal to one.

$$\begin{cases} u_j = \sum_k p_{jk} \cdot u_{jk}, \\ 1 = \sum_k p_{jk}, \end{cases} \quad k = 1, \ldots, K. \tag{8}$$

How to decide preferences' values, and calculate individual utility u_j has a room for improvement, but main objective is to confirm the effectiveness of the proposed framework.

We can think of many utility functions, and easiest functions are tt_j, wt_j and mt_j. These are used in a process of making Pareto plan in P-SCE study. In a real theme park, visitors choose his/her own plan by considering more factors. We tried to express features like waiting by the proposed method. However, too many functions confuse experiments results. For example, we may overlook effective set of functions. Therefore, we use basic three functions and two unique functions which represent features of how to wait. Five utility functions are defined as follows:

$$\begin{aligned} u_{j1} &= -wt_j, \\ u_{j2} &= -mt_j, \\ u_{j3} &= -tt_j, \\ u_{j4} &= -\left(wt_j^{\max} - wt_j^{\min}\right), \\ u_{j5} &= -\left(wt_j^{\min} - wt_j^{\max}\right). \end{aligned} \tag{9}$$

In u_{j1} to u_{j3}, each shorter time increases each utility respectively; longer waiting time wt_j decreases u_{j1}. Unlike others, u_{j4} and u_{j5} represent the characteristic of a way to wait in a queue. The visited attractions by each user have different waiting times, and these waiting times are simply classified as two patterns: one is average, and the other is bias. Large u_{j4} means that user a_j prefers how to wait averagely. Large u_{j5} means that user a_j prefers biased waiting times in which there is a large difference between the minimum waiting time and the maximum waiting time. In addition, only u_{j5} has a positive value.

Finally, when the number of utility functions K is equal to one and $u_{jk} = -tt_j$, the individual utility is equivalent to the travel time. This is that the objective of W-SCE is to minimize the travel time; therefore, W-SCE is equivalent to SCE. This means that our proposed method is the more general and practical framework to optimize a social system.

4. **Experiments and Discussion.** We verify the effectiveness of our proposed method through two experiments using the theme park multiagent simulation.

4.1. **Setting.** We modeled the same theme park as previous studies (see Figure 1) [4,5]. The number of attractions is 10, and 9 roads connect each attraction. Each user has to visit 4 attractions until arriving at the destination. In this model, there are not any popular attractions; therefore, the randomly given attractions are chosen uniformly. Simulation time t is incremented by one after all users behave.

In each experiment, the simulation setting about the behavior of user appearance which is based on SCE is classified into five types: $(N, \lambda) = (1000, 0.1), (2000, 0.2), (3000, 0.3), (4000, 0.4), (5000, 0.5)$.

All users have finished entering theme park until about 10,000 steps in each setting. For example, the N-th user enters the theme park about 10,000 seconds (approximately 3 hours) after starting the simulation when unit step is equal to a second.

In the same setting, we conducted the two types of estimation, SCE or W-SCE, for the comparison. The planning interval $interval_j$ is set to 300, and the results are the averages of 50 simulations. In preliminary experiments, results that set randomly value for p_{j1}, p_{j2} and p_{j3} were almost the same as SCE. Therefore, we set $p_{j3} = 0$ to reduce the dependence on one value.

4.2. **Experiment 1.** In this experiment, we set that the number of utility functions is two, because the waiting time and the moving time are important for each user. This setting is equivalent to $p_{j3} = p_{j4} = p_{j5} = 0$ in Equation (8), and most simple extended model of SCE. In the case $p_{j1} = p_{j2}$, user a_j puts emphasis on the travel time because the travel time is nearly composed of moving and waiting time.

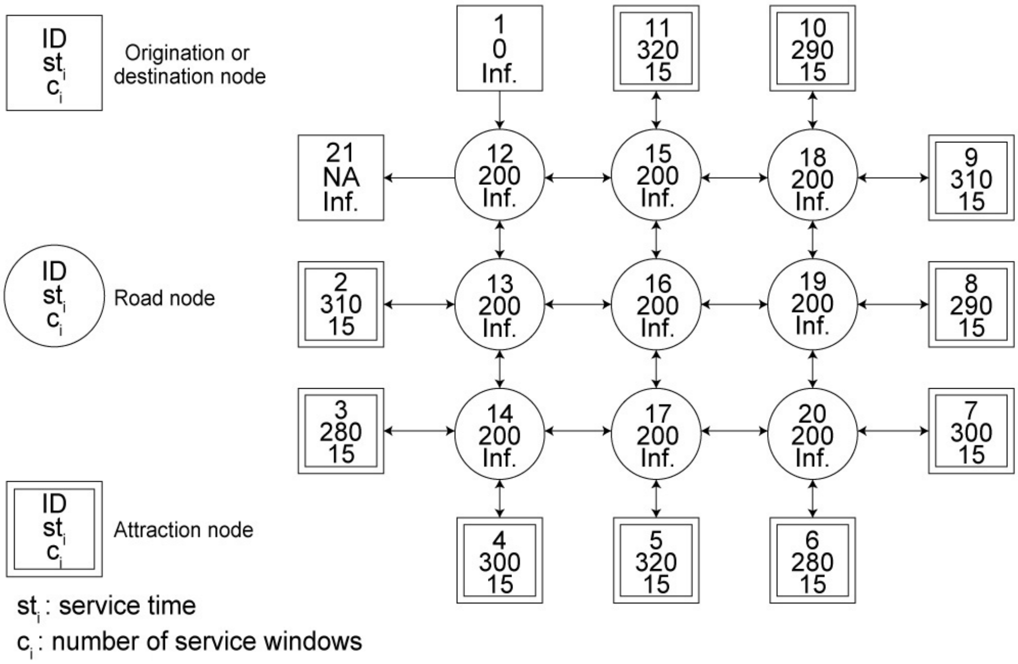

FIGURE 1. Theme park model composed of 10 attractions, 9 roads, one origination and one destination (This model is based on Figure 3 of [4])

TABLE 1. The results in the setting users consider wt_j and mt_j. In each U/N (SCE) or U/N (W-SCE) cell, the upper numbers are the average utilities, and the lower are the standard deviations.

(N, λ)	$(1000, 0.1)$	$(2000, 0.2)$	$(3000, 0.3)$	$(4000, 0.4)$	$(5000, 0.5)$
U/N (SCE)	−1399.7 (19.7)	−3306.3 (70.0)	−6006.2 (114.7)	−8748.0 (137.5)	−11498.1 (157.5)
U/N (W-SCE)	−1399.5 (20.4)	−3185.8 (78.9)	−5868.4 (105.3)	−8642.7 (143.1)	−11374.0 (210.2)
Ratio (W-SCE/SCE)	99.98%	96.35%	97.71%	98.80%	98.92%

TABLE 2. The results in the setting users consider wt_j and mt_j. In each TT/N (SCE) or TT/N (W-SCE) cell, the upper numbers are the average travel times, and the lower are the standard deviations.

(N, λ)	$(1000, 0.1)$	$(2000, 0.2)$	$(3000, 0.3)$	$(4000, 0.4)$	$(5000, 0.5)$
TT/N (SCE)	3988.1 (18.8)	7820.4 (137.2)	13219.8 (232.6)	18711.6 (262.9)	24212.4 (281.3)
TT/N (W-SCE)	3998.7 (22.7)	7849.2 (159.0)	13252.3 (200.1)	18786.5 (285.3)	24260.0 (392.6)
Ratio (W-SCE/SCE)	100.26%	100.37%	100.25%	100.40%	100.20%

Table 1 shows the average utilities and the standard deviations. In the both cases of $(1000, 0.1)$, the average utilities take similar values. Similar results are obtained about the average travel times (Table 2). In this setting, the theme park has the enough capacity to deal with users. The W-SCE in $N = 2000$ can increase about 3.7% of the average utility against SCE. In $N = 5000$, there is the improvement of the average utility only about 1.1%; however, W-SCE increases the large total utility of all users than other settings.

The utility is most important for users, but too inefficient use of the service is undesirable for the theme park. Table 2 shows the average travel times which are one indicator that represents the efficient use and the standard deviations in each setting and cost estimation. In all settings, the average travel times in case using W-SCE increase, however, they are almost the same. These results show that W-SCE can enhance the social welfare without interrupting the efficient use.

4.3. **Experiment 2.** W-SCE can depict various users by changing the set of u_{jk} and p_{jk}. W-SCE can represent more detailed individual characteristics. For example, how to wait in a queue list can be represented by considering u_{j4} or u_{j5}. Moreover, a user may place emphasis on u_{j1} and u_{j2}, but another may place emphasis on u_{j1} and u_{j3}, not u_{j2} at all.

To approach a practical setting, we took a survey on 80 people about how to wait in a theme park. Consequently, the percentage of users who prefer how to wait averagely is 32.1%, and the percentage of users who prefer biased waiting times is 67.9%. The preferences' values of the former are $p_{j3} = p_{j5} = 0$ in Equation (8), and the ones of the latter are $p_{j3} = p_{j4} = 0$ in Equation (8). The other p_{jk} are randomly determined according to Equation (8). Table 3 shows the results of the average utilities. First, the results in $N = 1000$ were concluded as not important in previous studies and Experiment 1. The W-SCE can increase the social welfare in all settings. W-SCE can increase the average utility about 4.6% in $N = 2000$, and about 1.8% in $N = 5000$.

Table 3. The results of Experiment 2. In each U/N (SCE) or U/N (W-SCE) cell, the upper numbers are the average utilities, and the lower are the standard deviations.

(N, λ)	$(2000, 0.2)$	$(3000, 0.3)$	$(4000, 0.4)$	$(5000, 0.5)$
U/N (SCE)	−2024.5 (54.9)	−3525.5 (87.4)	−5062.4 (101.1)	−6526.0 (156.6)
U/N (W-SCE)	−1930.3 (51.5)	−3423.9 (78.7)	−4911.4 (84.9)	−6407.5 (137.2)
Ratio (W-SCE/SCE)	95.35%	97.12%	97.02%	98.18%

Table 4 shows the results of the average travel times. In this experiment, we discover the trade-off between the utility and travel time. Enhancing both utility and efficient use of socially shared services is an aim of mass user support, and a future task. These results show that W-SCE can increase the social welfare with considering more real situations.

Table 4. The results of Experiment 2. In each TT/N (SCE) or TT/N (W-SCE) cell, the upper numbers are the average travel times, and the lower are the standard deviations.

(N, λ)	$(2000, 0.2)$	$(3000, 0.3)$	$(4000, 0.4)$	$(5000, 0.5)$
TT/N (SCE)	7820.2 (160.9)	13214.4 (200.0)	18794.3 (233.2)	24233.5 (344.5)
TT/N (W-SCE)	7895.9 (166.2)	13671.1 (176.5)	19607.9 (187.1)	25540.5 (194.2)
Ratio (W-SCE/SCE)	100.97%	103.46%	104.33%	105.39%

5. **Conclusions.** This paper has proposed a method that enhances social welfare while guaranteeing the individual utilities of visitors in theme parks. The previous works, SCE and P-SCE, cannot consider the individual utilities, which are usually different from each

other. Therefore, we have defined weights of the utility functions as preferences p_{jk} and expressed the individual utility function which is different in each user by calculating with p_{jk}.

The experiments reveal W-SCE, our proposed framework, can increase the social utility. W-SCE can handle various sets of visitors who have various preferences and increase the total of their individual utilities. The results of the experiments show possibility of mass user support in theme parks.

As a next step, we will focus on visitor's models composed of many types of users, how to decide preference value, and coordination by a central system like P-SCE.

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