Incorporating Matching Mechanisms into Market Design for Rehabilitation Reservation System

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INCORPORATING MATCHING MECHANISMS INTO MARKET DESIGN FOR REHABILITATION RESERVATION SYSTEM

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ABSTRACT

This study aims to design a matching mechanism to improve the utilization rate of rehabilitation bus. The existing operation mode of rehabilitation bus in Taiwan is divided into two types: partial government subsidy and full self-payment. The partial government subsidy type is operated by local government agencies or entrusted agencies. Users need to make an appointment by phone or register online in advance; however, limited transportation capacity and excess demand requests during the peak time slots overwhelmed the entire reservation system. The proposed model is similar as the Boston mechanism, which is called priority matching in market design. The deferred acceptance algorithm used in this study is a two-sided matching mechanism. From the perspective of the demander, passengers can choose the preferred order of boarding schedules at the time of the consultation, while the service vehicles are dispatched based on the passenger's disability level as the priority.

Keywords: Market Design. Deferred acceptance algorithm. Rehabus. Preference. Priority

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1. INTRODUCTION

In 2018, the elderly accounted for more than 14% of the total population in Taiwan, R.O.C. It is estimated that it will enter a super-aged community in 2025. According to the definition of the World Health Organization, 20% of Taiwanese people would be over 65 years old. In September 2016, the Taiwanese government passed the "Long-term Care Ten-Year Plan 2.0", which aims to promote the overall care service system in the community and realize the local aging policy to cope with the long-term care problem in the elderly.

Located in the eastern Taiwan, Hualien is a long and narrow terrain from north to south, with a total area of 4,628 square kilometers. It is the largest county-level administrative region in Taiwan. According to the information from the Hualien County Government Office, in March 2022, the total population of Hualien was 320,405. The population over 65 years old is 59,376, accounting for 18.5% belonging to the elderly. There are 26,489 people with disabilities, accounting for 8.2% of the total population. About 220,000 people live in four townships in northern Hualien County - Hualien City, Ji'an Township, Xincheng Township， and Xiulin Township.

Since the medical resources in eastern Taiwan are extremely scarce (i.e. only one medical center, and two regional hospitals,) the relatively incomplete medical sub-disciplines of the district hospitals and the public's preference for going to a large hospital, the load on the rehabilitation and long-term buses is on the high side.

The Hualien County Government entrusts the Mennonite Social Welfare and Charity Foundation, a consortium, to undertake the operation of rehabilitation buses and long-term care buses. The foundation owns 25 rehabilitation buses and 12 long-term care buses; in addition, three of its operators are supported by the Hualien County Government and entrusted to operate the long-term bus. Taking the 109-year data provided by Mennonite Foundation as an example, Hualien is divided into three districts. The northern district is Hualien City, Ji'an Township, Xincheng Township, Xiulin Township， and Fengbin Township; the central section is Shoufeng Township and Fenglin Township. Guangfu Township and Wanrong Township; the southern area is Yuli Township, Ruisui Township, Zhuoxi Township， and Fuli Township. In terms of the carrying capacity of Rehabus, the passenger rate of the North District is 73.6%, the Central District is 10.6%， and the South District is 14.5%, with an average of 2,498 trips per month and an average of 120 per day based on five working days per week. However, in April 2019, the Free Times reported that Hualien County's rehabilitation buses were eliminated due to old age and faced the dilemma of a lack of vehicles.

This study analyzes the allocation of rehabs and passengers from the market design perspective. The market design theory is research on resource allocation that cannot be priced—pairing between kidney transplants. This research is divided into five chapters. The second chapter is the literature review, which will analyze the related literature on rehabs, market design， and preference choice; the third chapter is the research method, which discusses the definition of models and variables; the fourth chapter is the simulation Verification; the last chapter is conclusion and discussion.

2. LITERATURE REVIEW

2.1 Rehabus

The Taiwan Rehabus fleet was first evaluated and promoted by the Eden Social Welfare Foundation and Professor Lawrence Lan. According to the information on the foundation's website, it was entrusted by the government to handle its business in 1990 to provide barrier-free transportation services for people with disabilities. Huang & Lin (2020) mentioned three difficulties in developing rehabilitation buses in Taiwan: insufficient number, limited reservation time and service targets of local governments, and first-come-first-served reservations, which make it impossible for people with disabilities to enjoy the service entirely. Wu & Chen (2016) took Taiwan Duofu Rehabus as an example and discussed the operation of Rehabus with a multi-income model and the provision of more flexible and high-quality services for the disabled. Hanson, Goudreua & Copp (2018) Using a community volunteer driver program and a transportation planning tool to assist seniors with transportation needs. Wu, Liu & Yuan (2020) established a multi-customer-centric transportation booking platform based on Taiwan Eden Foundation.

Through information disclosure, users can obtain the required resources in real-time, making practitioners easier to manage.

2.2 Market Design

Since people invented currency as an agent, market transactions are primarily based on its current primary barter model. However, some markets cannot use currency as an agent for transactions, so it needs to be designed to achieve the purpose of the transaction, For example, college admissions issues, organ transplant issues, etc. In many countries, organ trading is prohibited, but the law allows organ donation. In addition, organ transplantation must meet relevant physiological conditions, so even if an organ has been obtained, it cannot be matched if it does not meet the requirements. Gale & Shaply (1962) used the Deferred acceptance algorithm to deal with the problem of male and female matching, extended it to the problem of college admission, and proposed to increase the number of schools to deal with the issue of one-to-many; Roth (1985) suggests that the case of male and female is one-to-one Matching, while the school admission problem is a one-to-many pairing. Sheply & Scarf (1974) mentioned that Gale has demonstrated the Top trading cycle algorithm and proved that this method could produce stable allocations. Roth, Sönmez & Ünver (2004) applied the Top trading cycle to kidney exchange transplant pairings. Kojima, Shi & Vohra (2020) divide market design into one-sided matching and two-sided matching. Bilateral pairing is mainly based on a Deferred acceptance algorithm, and both sides have preferences. Although there are two groups of unilateral pairing, one of them is paired. There is no preference on the other side, and the Top trading cycle is the main one. In this study, because passengers prefer time selection, and Rehabus has a demand preference for passengers, it is bilateral matching. The Deferred acceptance algorithm is used as the primary research of matching. Abdulkadiroglu & Andersson (2022) mentioned that Pareto Efficiency, stability, and strategy-Proofness could be used as indicators to measure the goodness of the matching algorithm. Abdulkadiroglu & Andersson (2022) mentioned that any tiebreaker breaks the school's tie for student ranking; the Deferred acceptance algorithm is stability and strategy-proofness to students, while the Top trading cycle is for students, It is with; Pareto Efficiency and strategy-proofness.

2.3 Preference and Priority

Preference is significant in the field of market design. The market needs design because there is no currency in this market to measure the value of both parties in the transaction. Golden Tree (2005) Strict preference means that consumers clearly express that A is better than B, and a symbol represents it, that is, $A \succ B$; weak preference means that consumers think that A may be better than B, or A may be at least as good as B, which is expressed as $A \succsim B$. Consumers believe that A is as good as B, which means that A and B are indistinguishable, A symbol represents, that is, $A \sim B$. Druckman & Lupia (2000) Preference does not occur suddenly, but arises from the interaction between the individual and the environment. Dhar, Nowlis, & Sherman (1999) mentioned that consumers' similarities, differences, and preferences for the same options would change according to different tasks and circumstances. The comparison process will affect the priority. Hansson (1995) thinks that preferences are not static, and their preferences may have four types of preferences: revision, restriction, addition, and subtraction. Öztürké, Tsoukiàs, & Vincke (2005) proposed the kind of preference, which can be divided into the basic structure [P I], extended structure, and valuable structure, among which comprehensive structure can be divided into three types—$[P\ Q\ I]$、 $[P_1 \dots P_n]$ and Not comparable; and preferences can be sorted by options of certain/uncertain and strong/weak. Bailey (1993) proposed that performance and preferences are not necessarily correlated. Bailey cites a system that is well designed but dislikes the system because of personal preferences. Based on the above, individuals generate preferences because of the environment or tasks, which can be sorted, but preferences may change. In addition, the pros and cons of products are not necessarily directly related to preferences. Therefore, in the part of preferences, this study will Virtually with fixed preference discussions for the passenger and Rehabus to reduce the uncertainty of the situation discussion.

3. RESEARCH METHODOLOGIES

This study uses the Deferred acceptance algorithm proposed by Gale and Shaply (1962) as the basis and the simplified model of Balinski & Sönmez (1999) as the variable reference for this study. Selection, hospital and residency, and patient-ventilator pairing during Covid-19 extend to rehabus-patient pairing; However, the algorithm is widely used in many fields and is inconsistent with this study. There are some differences, so this study will readjust the variables to meet the needs of the study.

The Deferred acceptance algorithm is a two-sided matching. This study uses passengers and a rehabus as two sides of the pairing. A group of passengers $N = \{t_1, \dots, t_{|N|}\}$ apply to a set of rehabus schedules $S = \{s_1, \dots, s_{|S|}\}$, each rehabus schedule has a quota for application. q_s Passengers represent the number of seats for schedule shave a strict order of preference for schedule selection. The ranking of passengers on the rehabus will be based on the level of disability or other measurable criteria as a priority reference, as described by Abdulkadiroglu & Andersson (2022), by exogenous. The quantifiable criteria are used as the basis for sorting, called non-strategic, and the preference order is based on personal preferences. It cannot be verified, which is called strategic. In this study, passengers' preference for Rehabus schedules is non-strategic, while passengers' preference for Rehabus schedules is strategic.

Each passenger $i \in N$ has a strict preference P_i for the rehabus schedule, including no matching to the schedule, that is, denoted by $S \cup \{i\}$, $\{i\}$ represents that the passenger i is not assigned to the schedule. If sP_is', it means that passenger i likes schedule s more than schedule s', and "at least like it," it is represented by R_i, and the relationship between P_i and R_i is as follows:

$$sR_is' \Leftrightarrow sP_is'\, or\ s = s'$$

The priority order of passengers for each rehabus schedule $s \in S$ includes no matching passengers, namely $N \cup \{s\}$, and the order with weak preference $\gtrsim_s$, $\{s\}$ indicates that the schedule s has no matching passengers. If $i \gtrsim_s j$, it means that the rehabus schedule s likes passenger i slightly more than passenger j, or likes passenger i as much as passenger j.

The parameters of this study are summarized as follows:

- A set of passengers $N = \{t_1, \ldots, t_{|N|}\}$
- A set of rehabus schedules $S = \{s_1, \ldots, s_{|S|}\}$
- The quota for each shift $s \in S$ is q_s
- Each passenger $i \in N$ has a strict preference order P_i for $S \cup \{i\}$
- For each shift $s \in S$, there is a weak preference order $\succsim_s$ for $N \cup \{s\}$

4. SIMULATION VERIFICATION

This study is based on the schedule data of rehabilitation buses from June to December 2016 provided by the Hualien Mennonite Foundation as a reference for model planning. There are 9533 records in total, of which July 1 of the year is the maximum passenger load the patient designates. There are 66 trips from the location to the medical hospital, 64 visits from the medical institution to the selected area of the patient, a total of 130 visits, and the foundation has a capacity of 25 rehabilitation buses in that year, with an average of 5.2 round trips per bus per day. Based on the above data, the following assumptions are made in this experiment.

To simplify the model, take the one-way journey from the designated location of the patient to the medical institution as an example. The set appointment time is divided into 8:00-11:30 in the morning and 1:00-4:30 p.m. every half an hour; there are four rehabilitation buses scheduled for each shift, with a total of 64 bus seats, 25 vehicles are expected in turn, and each car leaves an average of 2.56 trips. After inquiring with Mennonite Foundation, the success rate of rehabus reservations is about 90%. Therefore, it is assumed that 72 patients are applying, and each has the qualifications for physical and mental disabilities. The capabilities for physical and mental disabilities in Taiwan are divided into very severe, severe, moderate, and mild However, this study assumes that each patient has a disability level of 0 to 100, with 0 being very soft, 100 being significantly severe, and those with scores above 60 is eligible to apply for a rehabus. The level of disability is 60~100 points. Each patient can reserve a vehicle shift according to the registration number and choose four shifts.

In this study, the delayed acceptance algorithm is used to apply the patient's preference for the appointment time. Just as the student applies to school, the student has the most suitable and stable result, and the patient also has the most convenient and stable development. During the matching process, if the same score is encountered, Rehabus has a weak preference for patients, “like at least as much.” In this study, the first registration is given priority—the smaller the patient's number, the earlier the appointment. After matching, the following results are obtained, such as surface. Of the 72 patients who applied for the Rehabus, 61 were successfully matched, 11 were not reached, and there were still three places for the Rehabus. The main reason was that only one person chose this schedule. This is the "remote hospital theorem." This is proposed by Roth (1986) in matching hospitals and interns, which means that no one chooses a hospital, and in any stable matching, no doctors will go to it. Of the paired logarithms, 48 received the first-ranked shift, 10 received the second-ranked shift, 3 were the third-ranked shift, and only one was the fourth.

Table 1 Simulation results of assigning patients and rehabus with delayed acceptance algorithm as a stable matching mechanism

Shift	patient	handicap level	priority	Shift	patient	handicap level	priority	Shift	patient	handicap level	priority
s_1	t_{31}	92	1	s_7	t_{24}	87	1	s_{13}	t_{67}	96	1
	t_{70}	88	1		t_{62}	85	1		t_{32}	92	1
	t_{23}	84	1		t_{34}	77	1		t_{38}	89	1
	t_4	81	1		t_{69}	74	2		t_{27}	78	1
s_2	t_3	77	1	s_8	t_{60}	86	1	s_{14}	t_{21}	93	1
	t_{47}	73	2		t_{53}	83	1		t_{37}	84	1
	t_8	69	3		t_{11}	78	1		t_{72}	77	1
	t_1	68	2		t_{51}	77	1		t_{56}	70	1
s_3	t_{39}	94	1	s_9	t_{46}	81	2	s_{15}	t_{64}	95	1
	t_{55}	79	2		t_{16}	74	1		t_{25}	92	1
	t_{19}	77	2		t_{50}	69	2		t_{42}	87	1
	t_5	72	1		t_{10}	64	4		t_{26}	64	1
s_4	t_{65}	91	1	s_{10}	t_{40}	98	1	s_{16}	t_{22}	93	1
	t_{43}	87	1		t_{15}	95	1				
	t_{12}	84	1		t_{66}	87	1				
	t_{28}	81	1		t_{13}	81	2				
s_5	t_{45}	97	1	s_{11}	t_2	92	1				
	t_{71}	86	1		t_{54}	92	1				
	t_{29}	79	2		t_6	82	1				
	t_{14}	73	3		t_7	81	1				
s_6	t_{57}	96	1	s_{12}	t_{59}	79	1				
	t_{68}	95	1		t_{35}	76	2				
	t_{61}	94	1		t_{48}	73	1				
	t_9	90	2		t_{20}	70	1				
Patients who did not register successfully											
t_{17}、t_{18}、t_{30}、t_{33}、t_{36}、t_{41}、t_{44}、t_{49}、t_{52}、t_{58}、t_{63}											

5. CONCLUSION AND DISCUSSION

This research is only tested with an ideal model, but the actual situation still needs to consider the registration process and related supporting measures such as the level of disability. Because the original rehabilitation bus registration method is first come, first served, that is, after registration, it can be confirmed whether the application has passed. Still, this model Only after a certain number of applications can be matched according to the applicant's level of disability and the priority of the application shift. After completion, the patient will be notified whether the appointment is successful and the appointment time. Furthermore, because the law stipulates that the level of disability is divided into four grades, it is easy to have the same matching level during the matching process. In the future, round-trip journey matching, partition matching, and shared rides will be carried out. Further, consideration can be given to discussing transportation issues such as route planning, reducing the number of space-time journeys, and dynamic matching with other algorithms. It can provide a more efficient operating model for Rehabus.

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