ABSTRACT

Applying rehabilitation bus transportation service for medical treatment for elderly and disabled people is a common problem in most of countries, especially medical transportation service in rural regions. Those elderly and disabled people in rural regions are not only inconvenient to travel but also difficulty in in going out for medical treatment due to the long distances of medical institution. Hence, they tend to drive their own vehicles. However, owing to the degradation of their driving skills that might lead to traffic accidents and result in many social problems. The rehabilitation bus service becomes one of the most important parts in providing a good long-term care for the elderly and disabled people.

The routing problem of rehabilitation bus is not a new issue and has been studied by academic researchers or practically operating organizations. However, to the researcher’s best knowledge, the preferences of the users (patients) and consultations (clinic hours) have not been considered in those models. This study proposes a new matching structure with deferred acceptance algorithm. In this system, the hospital to matching patients’ clinic hour preference and then the rehabilitation bus service center to match the transportation service. The proposed two-step matching algorithm provides better medical service for these patients who need rehabilitation vehicle service because not only the transportation needs but also the clinic how preference are considered. Results of this study show the two-step matching algorithm would benefit the whole medical service.

We examine the service reservation process of the Hualien rehabilitation bus transportation and its current vehicle dispatching system. Besides, we obtained data from the Hualien Mennonite Foundation from June 2016 to December 2016. So far, the dispatching center in Hualien still has relied on a manual dispatching system to accept reservations, and then assign rehabilitation buses based on previous experiences. Our research simulates various scenarios with clinic hours’ preferences and health conditions preferences in the real context.

Keywords: Matching, Rehabilitation, User preference, Deferred acceptance algorithm
1. Introduction

In the twenty-first century, the transportation service for the elderly and disabled people has become one of the most significant social challenges. As the increase population of elderly population rapidly grows, there are more chances of having chronic diseases dysfunction and disability. Therefore, long-term care services will be enlarged. The 1961-2061 Population Ratio in Taiwan from the National Development Council indicates that since 1993 the elderly population has accounted for 7% of the total population, and the phenomenon is called aging society. Moreover, Taiwan’s Population Ratio shown in 2018 states that Taiwan has entered into an Aged Society. Moreover, it will become a Super Aged Society by 2025 (Figure 1.1).

Figure 1.1 Population Ratio in Taiwan (1961~2061)
Source: National Development Council (2016)

Apart from the policy, we inspect the conditions of public transportation in Hualien in Taiwan. Hualien is the largest county in Taiwan with a fairly small-scale population. It means that Hualien has a few public transportation options compared with other major metropolitan areas in Taiwan as shown in Figure 1.2. People normally consider the distance from their home to the local train station to be too far. Besides, they find public transportation too difficult to be used and they prefer to use their own vehicles, which is more convenient and less expensive. In brief, these are the reasons that many people in Hualien are unwilling to take public transportation. Hualien’s topography is also challenging. It is narrow and long in the north and the south with a scattered bus transportation network and a single railway line for public transportation. However, it brings difficulties on the elderly and disabled people who visit the hospitals or the clinics. The advantages of rehabilitation buses include the flexible of door-to-door routing, the ability to operate with small scale ridership, and reasonable prices. There was an imbalance of supply and demand. When supply is greater than demand, it may be the reason of the lack of users. On the contrary, Taiwan’s aging population has grown up rapidly since the Long-term Care 2.0 infrastructure is constructed. Therefore, we predict that demand is greater than supply.
in this situation.

![Figure 1. 2 Percentage of Mass Transportation Each County in Taiwan](image)

Source: Ministry of Transportation Communications, and Statistics Office (2017)

Our research will mainly address on the issues of total health condition scores, rehabilitation bus routing and dispatching efficiency. We will use deferred acceptance algorithm combined with carpooling to design a new rehabilitation bus dispatching algorithm and systemic process. In this case, only phone reservations will be accepted and reservations can be booked seven days in advance. Moreover, we will attempt to decrease the time that dispatching staff must manage the bus schedule and increase the efficiency of the dispatching system. After all, we will establish a matching platform between clinic hours and the people who need them, and dispatch rehabilitation buses.

2. Literature Review

2.1 Long-term Care

Long-term care refers to the people who need life assistance and related medical services over an extended period of time which exclude general medical treatment before diagnosis or emergency treatment. Long term care is especially necessary for the elderly, disabled people, and chronic disease patients.

In USA, the long term care (LTC) refers to a continuum of medical and social service care, which support the needs of people living with chronic health problem or disabilities who cannot care for themselves in daily life. LCT in the USA is primarily provided by the government through a program called Activities of Daily Living (ADLs). ALDs are comprised of six parts: bathing, dressing, using the toilet, transportation, caring for incontinence, and eating (McCall, 2001).

Germany’s LTC program focuses on mitigating the physical, mental, and financial
stress of the people who need care and assistance for a long period of time. LTC services are based on the principle of “Prevention and rehabilitation before care, out-patient care before inpatient care, and short-stay care before full-time in-patient care.” The agency give(s) home, respite, short-time care (Schulz, 2010).

The ultimate purpose of LTC in Japan is to achieve “maintaining dignity and an independent daily life routine according to each person’s abilities.” (Satoshi, 2013). There are several goals that Japan tries to achieve with their LTC program including: 1. Establish values to make society pay more attention to the elderly and they care they require; and 2. Efficient delivery of high quality user-centered long-term care services be it in-home care, institutional care, or community based care.

No matter what country users (patients) live in, the challenge of long term care is how to efficiently offer the care to those who needs it. Therefore, the mobility of medical service is the critical issue in establishing a comprehensive long term care system.

2.2 Dial-A-Ride Problem

Vehicle Routing Problems (VRP) has already been researched for decades and has been used in various fields such as logistics and transportation. Dantzig and Ramser (1959) first proposed the Vehicle Routing Problem (VRP) and they dealt with the optimal routing of a fleet of delivery trucks between service stations and the terminal. According to different VRP constraint extension, (VRP) can be classified into following categories:

1. VRP with Time Window (VRPTW)
2. VRP with Pickup and Delivery (VRPPD)
3. VRP with Pickup and Deliveries and Time Windows (VRPPDTW)

The latter environment VRPPDTW is called the dial-a-ride problem (DARP) with the time windows of preferred pickup and delivery times specified by the customers. Desaulniers et al. (2002) stated that disabled people and the elderly are the primary customers of dial-a-ride services.

For the dial-a-ride service, there are two types of time window. The first one is soft time windows, in which vehicles can arrive a range of time based on the customers requested arrival time. The second one is hard time windows, in which vehicles must arrive exactly on time based on the customers requested arrival time (Taillard et al.). The users’ requests if can be confirmed in advance of vehicle routing planning is called as a static problem. If the users’ requests are gradually revealed
while some vehicles are already on active routes, this vehicle routes have to be constructed and edited in real-time (Cordeau, 2003). This kind of vehicle routing is then called dynamic problem.

2.3 Deferred Acceptance Algorithm

Two-sided matching market uses a centralized mechanism to match the agents on both markets. Two of the important criteria for the design of such a mechanism are stability and strategy-proof. Gale and Shapley (1962) proposed their famous one-to-one matching market for college admissions and marriage market to lead a new direction of matching mechanism study. The mechanism they proposed, deferred acceptance algorithm (DA Algorithm), is a stable matching and is strategy-proof for the proposing side (Dubins and Freedman, 1981). Since then, the applications of deferred acceptance algorithm covered from labor markets to college admissions, including the national resident matching problem (Roth, 1984), as well as school choice programs in Boston (Abdulkadiroglu et al., 2005) and New York (Abdulkadiroglu et al., 2009).

Shapley and Scarf (1974) used the method of “top trading cycles” to find a stable matching of indivisible goods (e.g., a house) to people. Roth (1985) pointed out that Gale and Shapley (1962) treated the case of many-to-one matching (the college admissions problem) as essentially equivalent to the one-to-one matching (the marriage problem) would reach some erroneous conclusions.

Balinski and Sönmez (1999) proposed a matching model to mimic the college admissions practices in Turkey. The student placement mechanism used in Turkey at that time is not Pareto efficient and not strategy-proof. In Turkey’s case students could manipulate the matching results. Balinski and Sönmez (1999) modified the Gale-Shapley college admission model and upgraded to Gale-Shapley student optimal mechanism. This updated mechanism is a fair, strategy-proof, and second-best strategy-proof placement mechanism.

Abdulkadiroglu and Sönmez (2003) proposed the top trading cycles mechanism for school choice. They argued that in college admissions, schools themselves are agents which have preference over students. However, in school choices case, the schools are “objects” to be consumed by the students. The top trading cycles mechanism is also strategy-proof and an alternative solution for some placement problems.

The rehabilitation bus service medical resources distribution would be regarded as a matching market of two sides: the consultations (clinic hours) and users (patients). In a tradable market, the most efficient resource allocation is when the price and quantity are determined by the intersection of supply and demand. However,
in the rehabilitation buses market, it is not the case. The rehabilitation buses market is more like the college admissions market. Users (Patients) have various conditions for the needs of social welfare and consultations (clinics) provide assistants to users (patients) in a better way. Therefore, the rehabilitation buses market relies on a good matching process to improve efficiency. The purpose of this study is to propose an efficient matching platform for both sides.

3. Methodology

3.1 Problem Statement

Currently, the Hualien Mennonite Foundation is in charge of a rehabilitation bus transportation service. The service operates a total of 28 rehabilitation buses and each bus is equipped with fast lift cranes at the back of the bus to quickly and easily load and unload patients with wheelchairs. Each rehabilitation bus can only accommodate two wheelchairs at the same time. Inside the rehabilitation bus there are four folding chairs for care workers or family members to accompany the patient.

Every day the dispatching center staff will receive calls from users trying to make a reservation. Each reservation can be made at least one day before the customers requested arrival time (CRAT) and as early as 1~7 days ahead. After confirming a user’s identification, staff will record the required appointment data (e.g. date, time, address). Next, the staff will confirm if there are any available buses that can be dispatched. If yes, staff will dispatch a rehabilitation bus directly; if not, staff will place the user on a waiting list. Lastly, staff will compile the recorded reservations and attempt to arrange carpooling, based on their past experience with users scheduling habits, and schedule the dispatching sequence. In this time period, if someone cancels their reservation or the carpool arrangement releases extra seats, then staff will notify the first user on the waiting list and re-schedule the sequence. The day before user’s reservation date, staff will call the user and confirm all boarding information with them.

3.2 Monthly and Annual Demand

The Mennonite Foundation transportation service operates 28 vehicles that can satisfy the current demand of the 498 active users in the system. However, it is difficult to predict the demand levels at any given period of time. One conclusion that can be drawn is that due to the overall aging trend in Taiwan, millions of citizens will retire in future decades and the demand for rehabilitation bus service will increase. To better understand the pattern of demand I analyzed the demand data for the Mennonite Foundation transportation system for each month from June – December 2016. I coded the data such that the days align on the x axis and a pattern can be
identified. I accomplished this by coding each date as a day (Monday, Tuesday, …) and the week that the day appears in numerical order in the month (Week 1, Week 2, …) as seen in Figure 3. 1. This yielded a predictable demand pattern that could be used to forecast demand future demand.

According to Figure 3. 1 the demand is highest in the first three weeks of a month with demand falling in weeks four and five. There is also a predictable drop in demand over the weekends due to a lack of medical institutions that are operational on Saturday and Sunday. Because of this predictable drop in demand the Mennonite Foundation transportation service only operates 5 rehabilitation busses on Saturdays and does not operate any rehabilitation buses on Sunday. Another pattern that was identified was that demand dropped to zero on holidays and on day where natural disasters occurred, such as typhoons or earthquakes. These patterns are important for the creation of an effective routing system.

We can check annual demand for the number of disabled people in Taiwan and Hualien from Ministry of Health and Welfare in Figure 3. 2 and Figure 3. 3. Except 2017, the number of disabled people increases year by year in Taiwan from 2013 to 2018. Except 2018, the number of disabled people increases year by year in Taiwan from 2013 to 2017. We can see that the demand of medical services for disable people is increasing.

Figure 3. 1 Demand for Medical Services by Month and Day
3.3 Demand Distribution

Another factor of demand that is important to understand is the geographical distribution of users and medical institutions and the demands place on both. To better understand the demand and geographical distribution patterns, I analyzed the data of each user that was active in the Mennonite Foundation transportation system from June – December 2016. I identified where each user lived and grouped them by individual Townships in Hualien Country. Furthermore, I analyzed the medical institutions that each user would make appointments at. Lastly, totaled the number of medical institutions utilized by active users of the Mennonite Foundation transportation system and categorized them by individual Townships in Hualien Country as seen in Figure 3. 4.
Figure 3. 4 Demand Distribution of the Total Number of System Users and the Total Number of Medical Institutions Utilized by System Users Categorized by Township

The problem of uneven demand distribution and long travel distances cannot be fixed via regulation change at this time because of current government regulations that do not discourage this type of behavior. Therefore, the current system must be made more fair and efficient while keeping demand and demand distribution the same. I accomplish this through the introduction of two-step matching algorithm combined with deferred acceptance algorithm and dispatch algorithm into the Mennonite Foundation transportation service routing system.

3.4 Deferred Acceptance Algorithm

This study constructs the matching platform, as in Figure 3. 5. The details of this platform will be explained and discussed in the text.
Currently, manual long-term care vehicle assignment causes a few difficult circumstances. First, users (patients) need to make appointments a week in advance and they must wait a long time for appointment confirmation. Secondly, if users (patients) cancel suddenly, operators (drivers) cannot reroute buses efficiently which causes rehabilitation bus service resource waste. Thirdly, the assignment is first-come-first-served base.

In this study, vehicle routing is modeled as a matching-routing problem by deferred acceptance algorithm matching between users (patients) and consultations (clinic hours). For the aforementioned reasons, we apply the deferred acceptance algorithm as the core of the matching process to resolve the current trip-assignment problems.

In this section, we focus on introducing and explaining the core engine of matching algorithm, the deferred acceptance algorithm proposed by Balinski and Sönmez (1999) which modified form that of Gale and Shapley (1962). Our model’s parameters and symbols are listed in Table 3.1.

<table>
<thead>
<tr>
<th>Parameters</th>
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<tbody>
<tr>
<td>Set of consultations (clinic hours)</td>
<td>D</td>
<td>Set of users (patients)</td>
<td>P</td>
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<tr>
<td>Set of unavailable consultations (clinic hours)</td>
<td>O</td>
<td>Evaluation categories of health conditions attributes</td>
<td>H</td>
</tr>
<tr>
<td>Set of available consultations (clinic hours)</td>
<td>C</td>
<td>Evaluation score of the needs for users (patients)</td>
<td>f</td>
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<tr>
<td>The matching function</td>
<td>μ</td>
<td>Users (Patients) preference list of consultations (clinic hours)</td>
<td>A</td>
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Table 3.1 Parameters and symbols used in this study

The detailed descriptions of the functions and parameters are as follows:

The mathematical format for the set of consultations (clinic hours) is:

\[
D = \{d_1, d_2, \ldots, d_n\}
\] (1)

Equation (1) represents \(n\) consultations (clinic hours). All the consultations (clinic hours) are listed as \(d_1, d_2, \ldots, d_n\). Assume there are total 3 clinic hours, such as morning, afternoon, and night, then \(n = 3\).

Since some consultations (clinic hours) may not be available in a certain time. We assume the set of unavailable consultations (clinic hours) is:

\[
O = \{o^{d_1}, o^{d_2}, \ldots, o^{d_n}\}
\] (2)

In Equation (2), \(o^{d_1}\) represents the set of unavailable consultations (clinic hours) \(d_1\).
Since not every available consultations (clinic hours) can serve a certain user (patient). The set of feasible consultations (clinic hours) presents the clinic hours that can serve the certain users (patients):

\[ C = \{c^{d_1}, c^{d_2}, ..., c^{d_n}\} \]  \hspace{1cm} (3)

In Equation (3), \( c^{d_1} \) represents the set of consultations (clinic hours) \( d_1 \) can serve users (patients).

Assume there are \( m \) users in the whole system. Each user represents a patient. The set of users (patients) is:

\[ P = \{p_1, p_2, ..., p_m\} \]  \hspace{1cm} (4)

Equation (4) represents the total users (patients) in the society as a set.

The set of evaluation categories of health conditions of \( k \) kinds is:

\[ H = \{h_1, h_2, ..., h_k\} \]  \hspace{1cm} (5)

Each patient health condition is measured by patient’s health record or the judgement of the system operator.

\[ f = \{f^{p_1}, f^{p_2}, ..., f^{p_m}\}; \text{ and } f^{p_i} = \{f^{p_{i1}}, f^{p_{i2}}, ..., f^{p_{ik}}\}; i = 1,2, ..., m \]  \hspace{1cm} (6)

The meanings of Equations (5) and (6) are described below. Based on the category of health conditions attributes, system operator scales users (patients)’ needs for the rehabilitation bus. The health condition score would be regarded as a quantified measurement to compare the needs among users (patients). In our case study, we scale the users (patients)’ need from 1 to 4 in the slightest case to the most serious case. The higher health condition score means that the patient is more qualified for receive rehabilitation bus. The set of evaluation scales for the patient \( p_1 \) is represented by \( f^{p_1} \). \( f^{p_{11}} \) then is the scale of the attribute \( h_1 \) for client \( p_1 \).

This study also considers the preference of patient’s side. User (Patients) may have some concerns when they call in for consultations (clinic hours). To respect the clients’ preference, we assume the users (patients)’ preference list for consultations (clinic hours) is provided when patients file their applications. This list is as:

\[ A_p = \{A_{p_1}, A_{p_2}, ..., A_{p_m}\} \]  \hspace{1cm} (7)

\( A_{p_i} \) is the user (patient) \( p_i \)’s preference list of those consultations (clinic hours).

The matching function \( \mu: D \rightarrow H \) where \( \mu(d) \) is the categories of health condition attributes required by consultations (clinic hours) \( d \). We assume that each patient has a strict preference on \( D \cup \{d_0\} \), where \( d_0 \) denotes that the patient rather have no consultations (clinic hours) than receive form hospital or clinic.

In addition, the set of consultations (clinic hours), the set of users (patients), the set of evaluation categories of health condition attributes, and the matching function
are fixed. The process of matching in this study is based on Gale-Shapley organization optimal algorithm as the core of matching mechanism for medical transportation service resource matching. Therefore, we do present a simple case in Table 3.2.

Table 3.2 Preference list between consultations (clinic hours) and users (patients)

We use a small case to demonstrate the matching results. In this small case, we assume there are three consultations (clinic hours) $d_1, d_2, d_3$. We assume there are ten users (patients): $p_1, p_2, \ldots, p_{10}$ in this case. The table of their preference lists for each other is presented in Table 3.2. The $p_n(z)$ $z = 1, 2, 3$, $z$ is the health condition of the patient $p_n$. Take $p_5(1)$ and $p_5(3)$ in Table 3.3 as examples, the health condition score of $p_1$ is 1 (the slightest case) and the health condition of $p_5$ is 4 (the most serious case). The $x$ in $(x, y)$ presents the consultations (clinic hours)’ preference list of users (patients); the $y$ in $(x, y)$ presents the user’s (patient) preference list of vehicles (drivers), the smaller number means the more preferred. The symbol ($\cdot$, $\cdot$) presents that matching is not feasible.

The detail of our deferred acceptance algorithm is following:

First, we define $p_m \succ d_n$ means user (patient) $m$ proposes to consultation (clinic hours) $n$; $p_m \prec d_n$ means user (patient) $m$ is rejected by consultation (clinic hours) $n$.

Every user (patient) proposes the most preferred consultation (clinic hours). $p_1, p_2, p_5, p_7 \succ d_1$, $p_3, p_6 \succ d_2$, $p_4, p_8 \succ d_3$

Every consultation (clinic hours) temporarily accepts their best proposer, and rejects other proposers to the number of quota. $p_1, p_7 \prec d_1$

Every user (patient) continually proposes the second-best consultation (clinic hours). $p_1 \succ d_2$, $p_7 \succ d_2$

Then, Back to step 2 until there is fully booked. $p_3 \prec d_2$, $p_3 \succ d_1$ $p_3 \prec d_1$
$p_3$ does not have the next-proposed consultation (clinic hours), and every consultation (clinic hours)'s quota is full, so the algorithm terminates.

The matching result for the simple case is the underline with shadow in Figure 4.1. After the matching, the consultation (clinic hours) 1 picks up the users (patients) 2 and 5. The consultation (clinic hours) 2 picks up the users (patients) 1, 6, and 7. The consultation (clinic hours) 3 picks up the users (patients) 4 and 8. And, the user (patient) 3 is not served.

### 3.5 Model Assumptions

In our research we purposed using deferred acceptance algorithm and dispatching algorithm and remodeled the entire matching process to serve users (patients) more fair and reasonable, reduce travel cost, and improve efficiency. First, we used deferred acceptance algorithm to design our new matching system. Second, we compiled the geographical coordinates (longitude and latitude) of the origin/destination (O-D) to acquire the real routing pattern and travel distance between the O-D. Third, we put data into our model which contained constraints to try and simulate the rehabilitation bus transportation service routing in Hualien County. After we ran the simulation the most efficient routes that can reduce the total travel distance, quantity of used vehicles and dead mileage can be selected through a systemic process. This process yields a much more efficient route while servicing the same demand level and minimizing three criteria compared with the original human calculated dispatching process.

Staff in the dispatching center answer ever incoming call and checks the system to determine if a reservation is available or not. If the reservation is available the system will approve and record the reservation then the staff member can give immediate confirmation to the caller. If the reservation is not available then the system will reject the reservation and the staff member can immediately recommend a different time or alternative transportation service. This immediate feedback increases efficiency and greatly increases user satisfaction because the system eliminates the uncertainty that existed under the old system. For every new reservation the system will calculate new routes and bus assignments then save the route temporary. If the system can accommodate the next reservation the previously saved route may change.
For example, a reservation that was assigned to Bus A may change to Bus B and the route for both buses might be reorganized to achieve optimum efficiency. If the system cannot accommodate the next reservation the system will generate the notification “Sorry, we cannot arrange a pick-up service for this time.” The dispatching staff can then help the caller choose an alternate time or recommend and alternate transportation service. The dispatching system can re-schedule the vehicle assignment and their routing under the constraints of fleet size when a new reservation request is received. We show remodel dispatching process by system in Figure 3.6. Limited rehabilitation bus resources create a condition where we believe human experience can’t dispatch rehabilitation bus precisely or effectively. In other words, at most levels of demand most of the rehabilitation buses will be dispatched. This over utilization of resources forces buses to cover large distances without riders (dead miles), increases operating cost, and lacks flexibility. Therefore, our model attempts to minimize total travel cost to optimize the efficiency of the rehabilitation bus dispatching problem (RBDP). Now we will define our algorithm, total travel distance, and the dead mileage function respectively.

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**Figure 3.6 Remodel Dispatching Process by System**

**Step I Consultation Matching**

1. Passenger Call
2. Hospital Appointments System
3. Confirm Identity
   - Patients Database
   - Input: Health Condition Scores, Clinic Hours Date/Time, Preference List
   - Deferred Acceptance Algorithm Matching
   - Make Another Appointment
   - Yes: Dispatching System

**Step II Rehabilitation Bus Matching**

1. Confirm Identity
2. Passenger Database
3. Input: Origin-Destination Appointments Date/Time
4. Dispatch Algorithm with Carpooling
   - No: Arrange to Waiting List
   - Yes: Scheduling Dispatching Sequence
   - Offer Accessible Wheelchair Taxi
5. Daily Dispatching Sequence List
4. Computational Result

4.1 Data Description

We obtained all of our data for the rehabilitation bus transportation service from the Hualien Mennonite Foundation. We extracted a total of 9,533 records from June-December 2016. All of the original data was written by hand. All of the data had to be manually extracted and typed into Excel. The data extracted was the UserID, appointment time, address of the origin and destination, mileage from the origin to destination, and vehicle number. Among them addresses of the Origin and Destination points, mileage was recorded based on the individual drivers own notation habits.

4.2 Results

4.2.1 Total Health Condition Score

We randomly pick 30, 60, and 90 users (patients) of destination to Hualien Tzu Chi Hospital by the Mennonite Foundation in each month from June-December 2016 is shown in Figure 4. 1 as averages of total health condition score. We assume health condition score from 1, 2, 3 and 4 in a ratio of reality situation. The system proposed by our study designs with deferred acceptance algorithm applying in school choice. The users are like students, and the consultations (clinic hours) are like school as well. The average varies from month to month, but it makes some discrepancies. However, in the situation of 30 users (patients) have 59 travels in June with total health condition score 4. Meanwhile, we calculate that 30 users (patients) from June to December about 55 to 59 travels all with total health condition score 4. Besides, it is close to reality number of Hualien Tzu Chi Hospital’s users (patients), and then we can provide rehabilitation buses to the most needed users (patients) in priority.

The systemic system could increase the health condition score by an overall average of 114%/month in 30-users situation; 99%/month in 60-users situation; 68%/month in 90-users situation. Averages of total health condition score are not related to month by month, but we can see when the number of travels increases, the scores between system and original will get closer. Moreover, if the demand is increased while keeping the total number of vehicles constant, then we can serve more lower score users (patients) with carpooling. This will directly reduce the total travel distance as well, resulting in lower fuel cost and an overall reduction in the total travel cost.
Figure 4. 1 Averages of Total Health Condition Score

4.2.2 Total Vehicles Used

The total number of vehicles used by the Mennonite Foundation in each month from June-December 2016 under the original human dispatch system by our simulation is shown in Figure 4. 2. The total number of vehicles used varies from month to month. However, the total number of vehicles used never exceeded 17 and was never less than 15 in 30-users situation; the total number of vehicles used never exceeded 34 and was never less than 30 in 60-users situation; the total number of vehicles used never exceeded 52 and was never less than 49 in 90-users situation. The systemic system could reduce the total number of vehicles used by an overall average of 45.95%/month in 30-users situation; 36.75%/month in 60-users situation; 40.1%/month in 90-users situation. The vehicles that are idle after the implementation could be used to expand operations to serve more users as the demand increases. Every day the foundation can serve as many as 14 users (patients) with about 7 rehabilitation buses. Excluding Sundays (52 days) and national holidays (11days), the rehabilitation buses can annually serve as many as 4,186 users (patients). With optimized dispatching this capacity could be realized instead of being wasted.

Total vehicles used are directly related to total travel cost through the other two variables: total travel distance and dead mileage. By reducing the total number of vehicles used, the number of trips traveling back to and from the depot with no passengers (dead mileage) is reduced. Moreover, if the total number of vehicles is decreased while keeping demand constant, then carpooling will likely increase to satisfy the demand more efficiently. This will directly reduce the total travel distance as well, resulting in lower fuel cost and an overall reduction in the total travel cost.
4.2.3 Total Travel Distance

The total travel distance of all vehicles used by the Mennonite Foundation in each month from June-December 2016 under the original human dispatch system by our simulation is shown in Figure 4.3. It also shows the projected total mileage of all vehicles if the foundation implemented the systemic dispatching system. If the drivers follow the route generated by our system, the foundation could save more than 13,412.29 kilometers/year of travel distance in 30-users situation; 28,417.81 kilometers/year of travel distance in 60-users situation; 50,313.16 kilometers/year of travel distance in 90-users situation. This not only reduces the maintenance expense but also reduces the fuel expense.

Total travel distance is far less dependent on the other two variables: total vehicles used and dead mileage. If the demand remains constant, then total travel distance is only variable because of the difference in routes that the drivers take. For example, if the same user makes the same appointment every week and driver A picks them up using his own personal route; then driver B picks them up the following week using their personal route, the total travel distance could differ by as much as 10%. Therefore, we implement OSRM to eliminate this variability and route each driver in the most efficient way possible. This reduces the total travel distance which then contributes to reducing the total travel cost.
The total dead mileage of all vehicles used by the Mennonite Foundation in each month from June-December 2016 under the original human dispatch system by our simulation is shown in Figure 4. It also shows the projected dead mileage of all vehicles if the foundation implemented the systemic dispatching system. If the drivers follow the route generated by our system, the foundation could save more than 277,955.1 kilometers/year of dead mileage in 30-users situation; 628,897.9 kilometers/year of dead mileage in 60-users situation; 938,526.7 kilometers/year of dead mileage in 90-users situation. Therefore, the total travel distance and dead mileage saved by using the systemic routing system is 291,367.4 kilometers/year in 30-users situation; 657,315.8 kilometers/year in 60-users situation; 988,839.9 kilometers/year in 90-users situation. This not only reduces the maintenance expense but also save money for fuel. Given the average cost of diesel in Taiwan in 2016 was $19.6/L and the average efficiency of all rehabilitation buses is 14.3km/l. The foundation stands to save $382,811.8/year in 30-users situation; $900,936.3/year in 60-users situation; $1,355,333.1/year in 90-users situation in fuel alone.
This study analyzes the Hualien Mennonite Foundation transportation service and the existing human centric dispatch system used for reservations, matching clinic hours and patients, bus routing, and planning. We then used the data we gathered to develop two-step matching algorithm that concludes deferred acceptance algorithm and dispatching algorithm with carpooling. Then, vehicle routing data to calculate the most efficient routing of the rehabilitation buses based on their limited resources. The two-step matching algorithm attempts to maximize total health condition scores with users’ (patients’) consideration of consultations (clinic hours) in first step, then maximize efficiency by reducing three key factors: the number of vehicles used, the total route length, and the total dead mileage driven in second step. After running 30-users, 60-users, and 90-users in different month simulations, we were able to greatly increase total health condition scores and efficiency through the use of our two-step matching algorithm after our conclusions are as follows:

1. Under the human dispatching system, users could only be served if a reservation was successful by first call first in. Otherwise, due to the more serious users (patients) could book before the more light ones do, medical transportation service could be wasted if the more serious users (patients) cancel or book many services in different rehabilitation bus operators.

2. The systemic system could increase the health condition score by an overall average of 114%/month in 30-users situation; 99%/month in 60-users situation; 68%/month in 90-users situation. Besides, 30-users situation is

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5. Conclusion

Figure 4. 4 Dead Mileage

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close to reality number of Hualien Tzu Chi Hospital’s users (patients), and then we can provide rehabilitation buses to the most needed users (patients) in priority.

3. Assuming the same demand levels, the systemic dispatching system only utilizes 45.95% of the vehicles compared to human dispatching system in 30-users situation. Therefore, the remaining 54.01% of vehicles can be used to service more patients

4. If all rehabilitation bus drivers adhere to route specified by our two-step matching system, the foundation could save 13,412.29 kilometers/year of travel distance in 30-users situation. Systemic dispatching can also reduce dead mileage by 277,955.1 kilometers/year in 30-users situation. Therefore, the total travel distance and dead mileage saved by using systemic routing is 279,296.4 kilometers/year; the foundation could save $382,811.8/year in 30-users situation close to reality situation.

6. References

6.1 Journal Articles


Schulz, E. (2010). The Long-Term Care System in Germany.
