AN INTERACTIVE BUS SCHEDULING SYSTEM
FOR THE HANDYSCAT OPERATION

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AN INTERACTIVE BUS SCHEDULING SYSTEM
FOR THE HANDYSCAT OPERATION

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THESIS

Presented to the Faculty of the Graduate School of

The University of Texas at El Paso

in Partial Fullfillment

of the Requirements

for the Degree of

MASTER OF SCIENCE

THE UNIVERSITY OF TEXAS AT EL PASO

August, 1986

ACKNOWLEDGEMENTS

Several people were very important in the making of this thesis. Their influence and cooperation were greatly appreciated. I would like to thank the professors of Industrial Engineering at the University of Texas at El Paso; Dr. Robert Reid, Chairman of the Mechanical and Industrial Engineering Department and, in particular, my thesis advisor, Dr. Po-Wen Hu. Dr. Hu's guidance and example will remain with me throughout my engineering career. I also wish to thank my other two thesis committee members, Dr. Carroll Johnson and Dr. Anthony Tarquin. Dr. Johnson has been very influential on my development as a student and professional and I wish to convey my deep appreciation.

A deep feeling of gratitude is extended to my wife, Guadalupe Quintana, which without her faith in me, her love and total dedication this thesis would not have been possible. Furthermore, I would also like to thank my parents, Rolando P. and Hilda Quintana, for their love , support, and encouragement.

Finally, I would like to thank two classmates, Sergio de la Reza and Jesus Rene Villalobos whose friendship helped me bear some of the tougher moments, and made the good ones seem majestic.

ABSTRACT

An interactive computer program has been developed for the City of El Paso's HANDYSCAT transportation service. HANDYSCAT is a door-to-door bus service for the elderly and handicapped. The program uses a "greedy" heuristic algorithm which gives a good feasible bus schedule and allows for immediate trip request confirmation or denial. The resulting feasible schedule can be improved by a tour improvement batch program which is left as an area for future implementation. Furthermore, a rule-based algorithm is developed for estimating travel time from statistical means. The program was designed to run on a microcomputer and can be generalized for any city department requiring the pickup and delivery type scheduling as in the City of El Paso's HANDYSCAT operation. Although travel time estimation is city-dependent, the estimation algorithm developed can be easily generalized for application in other cities.

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INTRODUCTION

1.1 Overview of the HANDYSCAT Operation

HANDYSCAT is a special transportation service offered by the City of El Paso, which provides on-demand non-emergency transportation service for disabled citizens who are unable to use conventional public transportation. Most major cities in the United States have similar services.

Currently there are 10 buses, and their availability varies during any given day from 2 buses at non-peak hours to 10 buses, during the hours of highest demand. The availability is determined by the operating budget funded by the city. Moreover, the capacity of each bus is 13 non-wheelchaired passengers,and allows for a maximum of 3 wheelchaired passengers with 10 non-wheelchaired. Assistance for eligible handicapped passengers is usually provided by the bus driver during boarding and unboarding.

Three dispatchers are currently available for scheduling passenger request. No computer aids are provided at present. Passenger requests fall into 3 general request categories as follows:

(1) Reserved trips (6 weeks in advance),

(2) Seasonally fixed schedules (e.g., students at El Paso Community College), and

(3) Variable demand for next day service.

HANDYSCAT operates Monday through Friday, between 6:30 a.m. and 8:00 p.m., Saturdays between 9:45 a.m. and 8:00 p.m. and Sundays between 8:45 a.m. and 5:30 p.m. Passengers may schedule their appointments and return trips between those hours. If a delay is expected at a doctor's or other appointment, the HANDYSCAT office is informed and the customer's pickup time is re-scheduled.

Requests are prioritized from non-emergency medical, work, education and rehabilitation trips, personal business trips and lastly, shopping, recreation and other trips. Finally, passengers are expected to be ready for a pickup 15 minutes prior to their confirmed time, and the current policy permits a maximum bus waiting time of five minutes.

To schedule a trip, certified HANDYSCAT cardholders request service six weeks in advance of the date service is desired by calling the dispatching office and giving their desired pickup and delivery times, pickup and delivery addresses, and their identification numbers. These passengers are included in the tentative schedule for the particular day in question. The current policy calls for not accepting anymore service requests during the subsequent six week period until the day prior to service,

during which the service requests for the next day are accepted and scheduled.

Those passengers requesting service six weeks in advance cannot be confirmed at the time call is made due to the trip prioritized criteria. For example, with the current dispatching rules a passenger requesting a medical trip one day in advance can, in theory, bump another passenger requesting a shopping trip six weeks prior. This type of scenario, however, in practice happens quite infrequently. Furthermore, since all passengers are scheduled the day before service is requested, trip confirmations or denials are oftentimes made in the evening hours of that day; hence customers who are denied service find it frustrating to effectively change their plans.

As previously noted, HANDYSCAT provides non-emergency transportation to the elderly and handicapped citizens of the City of El Paso. Buses pickup these people at their residences and take them to their requested destinations. Return trips at later times are also possible. In addition to the origin/destination (O/D) constraints, other operating constraints include:

1) Capacity constraint - as previously mentioned, each bus allows for a maximum of 3 wheelchaired with 7 non-

wheelchaired passengers, or a maximum of 13 non-wheelchaired passengers without wheelchaired passengers.

2) Quality of service constraint - a passengers must not be on a bus for more than 1 hour plus the estimated travel time between his or her origin and destination. This constraint is artificially imposed to avoid an extremely long trip for any passenger.

3) Time-window constraint - the range of times in which a pickup and/or delivery must be made; a 5 minute time-window will be used.

Perhaps the most trivial problem encountered is the most frustrating to the dispatchers. That is, the entire scheduling procedure is performed manually. The overwhelming amount of paperwork results in little time for the critical aspect of the job: scheduling the buses in such a manner whereby constraints are satisfied and total vehicle mileage is minimized. Furthermore, the inherent "slowness" of the manual procedure creates inconveniences to the customers; most notably those variable daily demand passengers cannot receive confirmation for their requests until the evening hours. Time travel estimates, moreover, are made by the respective dispatcher's "experience" with the help of a city map and street locator guide.

Consistency of the dispatcher cannot be expected from new dispatchers who lack such "experience".

1.2 Overview of the Vehicle Scheduling and Routing Problem

1.2.1 Problem classification

The HANDYSCAT operation bus scheduling problem is known in transportation literature as the multi-vehicle pickup and delivery problem, or PUDP. The multi-vehicle PUDP is concerned with developing a set of routes for a fleet of vehicles serving customers requiring specified pickup and delivery points. The PUDP is thus a class of vehicle routing problem with the alterity that a vehicle must stop at a distinct origin which must precede a delivery at a distinct destination; i.e., the origin/destination (O/D) constraint. The problem is not a constrained version of the well-known Vehicle Routing Problem (VRP) [1] since in the latter, vehicle capacity is not an integral part of the problem, although it may be a key constraint.

The overriding consideration in the VRP is vehicle capacity and the objective is to deliver goods to as many locations as possible in the most economical manner. On the other hand, the predominant purpose in the PUDP is to satisfy the set of all (O/D) constraints, and as such, the

capacity has a different effect upon the optimal route. For PUDP, vehicle capacity must be checked at every stop on the particular route followed since remaining unused vehicle capacity decreases at pickups and increases when deliveries are made. Conversely, with the VRP, a fully loaded vehicle is assumed when it departs from the origin.

The Travelling Salesman Problem (TSP) [2] is another much publicized routing problem whose structure is inherently similar to the PUDP's. For a Travelling Salesman Problem, given an initial starting point, each stop must be visited only once and the route must end at the starting point. Therefore, the PUDP with the O/D requirement, can be considered a constrained version of the TSP with dependant pairs of points along the network.

The objective of the multiple vehicle TSP is to route the vehicles in such a way as to minimize the total travel mileage for all vehicles and determine the minimum number of vehicles needed for meeting delivery quantities and for certain nodes to be served on at least one route [3]. Since a distinct pickup must precede a distinct delivery in the PUDP, the constraints of PUDP differ from the TSP in that visitation order is a prime factor.

The PUDP arises in many routing situations other than transportation services for the disabled. For example,

courier services, military logistics, and futuristic multiple orbiting space situations require a distinct pickup to precede a distinct delivery stop in the routing of support vehicles. Nevertheless, the published literature on the PUDP is minimal compared to the TSP and VRP, which suggests that future developments are needed for this relatively unexplored area of vehicle scheduling and routing theory.

1.2.2 Problem difficulty

The PUDP is considered more complicated and at least as difficult than the TSP or VRP. Armstrong [3] has shown that one instance of the PUDP can be reduced to two travelling salesman problems. Hence, the implication is that since the computational complexity of the TSP is NP-Complete, the PUDP is also NP-Complete unless P=NP (for definition, see Karp [4]). P-class problems are those that can be solved in polynomial time. That is, if a network has n nodes the computational time required to solve the problem is, in the worst case, $O(n^k)$ where k is a fixed integer depending on the problem. NP-class problems, on the other hand, can only be solved in exponential time; i.e., the computational time required to solve such a problem is, in the worst case, $O(k^n)$, where n is the number

of nodes in the network and k is a fixed integer which depends on the problem. Consequently, NP-class problems reach a "combinatorial explosion" for those problems with a large amount of nodes.

Since there is no known polynomial time algorithm that can optimally solve the TSP or PUDP, it is unlikely that an exact algorithm can handle a problem the size of HANDYSCAT's efficiently and within a reasonable time frame. Thus, while exact methodologies have been developed in recent literature, the few large scale PUDP-type operations implemented have been using heuristic algorithms.

1.2.3 Problem significance

In the fiscal year 1985, total vehicle mileage travelled for the HANDYSCAT operation was 458,090 miles with fuel and maintenance costs over $450,000 dollars. Since nearly every major city provides transportation services to the disabled, each must allocate, depending on their size, a similar percentage of their budget to fund such services.

According to Armstrong [1], savings of from 5 to 10% are possible by applying computer assisted algorithms to solve vehicle routing problems. Since the PUDP is more complex in nature than the VRP due to the O/D constraints,

it is doubtful that a dispatcher can produce economical routes and schedules without assistant; hence, at least the same significant cost reductions can be expected. Furthermore, many cities, such as El Paso, do not have computerized databases to assist dispatchers in estimating travel time and distances and in keeping track of scheduling. Therefore, labor intensive dispatching also contribute in great part to the cost of providing transportation services and offer an excellent source of cost saving potential.

It is evident that from the size of the HANDYSCAT system, the voluminous demand from El Paso City residents, and the inherent difficulty in scheduling O/D constrained routes that the present methodology leads to inefficient use of resources and consequently, unsatisfied customers. Moreover, the population requiring use of such a service has been growing rapidly and, in lieu of recent fiscal reductions, a more efficient and responsive scheduling methodology is necessary to insure that disabled citizens continue to have access to reliable and affordable public transportation. Finally, the success of the proposed system can be generalized to include any city department requiring such constrained scheduling.

1.3 Objectives of research

This research has been conducted on a voluntary basis for the city of El Paso; i.e., no funding has been provided. The ultimate objective of the research is to improve the operation and reduce the operating costs of the City of El Paso's HANDYSCAT service. To achieve this objective, a computer program has been developed to reduce the dispatcher's manual chores through a customer information and city grid prototype database. The prototype database can be expanded for future large-scale implementation. The interactive program has been developed for the booking of passengers and scheduling of buses. The program can be run on a microcomputer.

A secondary objective is to generalize the proposed vehicle scheduling and routing system whereby any city department providing similar non-emergency transportation services can implement it efficiently and effectively. To achieve this objective, a modular system construction approach is taken in the design of the proposed system.

1.4 Organization of thesis

In Chapter 2 a detailed review of literature pertinent to the PUDP and in particular to the HANDYSCAT operation is presented. Both exact and heuristic algorithms are

described, although the major thrust is dedicated to computationally feasible heuristics.

In Chapter 3 an overview of the proposed system is given. The front-end program, database prototypes, travel time estimation procedures, and a tour improvement algorithm are discussed.

Chapter 4 gives a theoretical discussion of the components of the proposed prototype computerized scheduling system. Special attention is given to the travel time estimation procedure since it is imperative for the generalization of the algorithm. In Chapter 5 the system performance measures are described and analized as evaluation criteria for the adequacy of the proposed full scale computerized scheduling system.

Finally, recommendations, present limitations and future improvements to the proposed system, and possible generalizations are discussed in Chapter 6.

Chapter 2

LITERATURE REVIEW

Three articles and a dissertation which discuss the PUDP with exact and heuristic algorithms are reviewed in detail in this chapter. Psaraftis [5] developed a dynamic programming solution as did Armstrong [1], although the latter's is more efficient on heavily constrained problems. Psaraftis, moreover, in a 1982 article described a heuristic algorithm for the multi-vehicle dial-a-ride problem [6]. Finally, Hu and Johnson [2] developed and implemented a PUDP heuristic algorithm for the City of Arlington's HANDITRAN operation in 1982. The four aforementioned papers are the only ones reviewed because of their close relevance to the thesis topic.

2.1 Exact algorithms

2.1.1 Psaraftis (1981)

Psaraftis published an exact PUDP algorithm using dynamic programming in the May, 1980 issue of Transportation Science. He investigates the single-vehicle, many-to-many immediate-request dial-a-ride problem in both the static and dynamic cases. Many-to-many refers to the uniqueness of the pickup and delivery points of the individual customers, while immediate request implies that

every customer desires service as promptly as possible after the request is made. It should be emphasized that the HANDYSCAT system is considered an advanced reservation transportation service, not a dial-a-ride immediate request, which is similar to a taxi service. While it is easier to schedule advanced reservation trips due to the apriori knowledge of service requests and thus achieve "better" vehicle routes, both types of situations possess the same mathematical structure; i.e., that of the PUDP [2].

The static case refers to the inability of the single vehicle to alter its route once the servicing of customers commences. For example, should a request be cancelled during the route, the remaining stops would remain the same; i.e., a new optimal route for the remaining points would be unavailable. The dynamic component, on the other hand, would accommodate such changes, as well as ongoing customer requests, should they arise during the vehicle's tour.

A generalized objective function minimizes the weighted combination of the service time to all customers and the total degree of "dissatisfaction" experienced while waiting for service. A generalization of the objective function is that of the TSP, and is assumed linear with