A DYNAMIC VEHICLE-SCHEDULING PROBLEM

by

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ABSTRACT

This study applies Doll's formal decision rules to solve a dynamic vehicle-scheduling problem provided by ALLTRANS EXPRESS LTD. (Vancouver). Computer simulation is used as the research tool. The computer simulated results are compared with ALLTRANS solutions based on the perfomance measures of mean travel time per customer, mean and standard deviation of time to serve a customer, and mean and standard deviation of delivery time per customer. Doll's decision rules contain two scheduling heuristics, i e , closest customer heuristic and time saved heuristic, and a set of three dispatching decision rules associated with parameters ME, MB and S. It is found that Doll's decision rule methods do not improve the solutions in terms of reducing travel time per customer but can produce higher service quality in terms of reducing the time to satisfy a customer requirement after its occurrence. The general performance of Doll's decision rules on this specific situation indicates that:

(1) The time saved heuristic is more preferable in solving this problem.

(2) Both ME and MB can affect the performance measures described above, and combinations of these two parameters can control the trade-off between the mean travel time per customer and mean time to satisfy a

customer request after its occurrence.

(3) Geographical restriction which depends basically on the design of sectoring mechanism (S) can affect all five performance measures.

Further research should be done on testing the effects of the within sector condition (S) of the dispatching decision rules, with emphasis on the design of a specific sectoring mechanism. Also, with a larger size problem, further sdudies should be performed on the use of combinations of the dispatching decision rules to control the trade-off between mean travel time per customer and mean times to satisfy a customer request after its occurrence.

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C.C.H.	THE CLOSEST CUSTOMER SCHEDULING HEURISTIC
T.S.H.	THE TIME SAVED SCHEDULING HEURISTIC
ME	THE MAXIMUM EFFICIENCY INDEX
MB	THE MINIMUM BACKLOG
S	THE NUMBER OF SECTORS

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CHAPTER I

INTRODUCTION

A vehicle-scheduling problem involves developing schedules to serve customer demands at various locations with vehicles which travel to these locations. If the set of relevant factors such as the location of customers, customer requirements, number of vehicles and size of vehicles does not change as time progresses, the problem is classified as static vehicle-scheduling. On the other hand, if some of these factors do change as time progresses, then the problem is classified as dynamic vehicle-scheduling.

As pointed out by Doll[10], the vehicle-scheduling problem has received only limited benefit from the application of the set of techniques and theories called management science, in spite of the fact that it must be solved every day by many people in business and government. This lack is due to relatively little attention by researchers and managers, rather than the inappropriateness of management science. In his research, Doll developed a set of formal decision rules to solve a dynamic vehicle-scheduling problem and tested the general performance of these decision rules on a hypothetical problem by means of computer simulation.

To supplement Doll's study, the present thesis compares formal decision rule solutions with the solutions implemented in an actual situation. This actual business situation is simulated. In the simulation, schedules are developed according to Doll's formal decision rules and vehicles are dispatched to follow these schedules. Results from the computer simulation experiments are analyzed and compared with the actual implemented solutions. This enables an assessment of the factors for deriving fast delivery and high efficiency in customer services.

1.1 Objective of the Study

Most vehicle-scheduling problems attempt to minimize total travelling time and to minimize the time required to satisfy a customer's order under the conditions that total load allotted to each vehicle does not violate its capacity limit and the vehicles can complete all schedules within a time limit. Since customer requirements fluctuate during a working day according to changing location and varying amount of goods to be delivered, the scheduling problem is often dynamic rather than static.

Doll[10] recently made a study of the dynamic vehicle-scheduling problem. He developed decision rules to solve such problem and performed computer simulation on a hypothetical case in order to evaluate the performance of his decision rules. The present study makes use of Doll's decision rules to develop schedules and to dispatch available vehicles in accordance with these schedules so as to generate solutions that satisfy a set of customer order actually received by a transportation company. The generated solutions are then compared with the implemented solutions which are derived from the experience of the company. The objectives of this study are therefore as follows:

(a) to test the suitability of the application of Doll's decision rules on an actual business situation;

(b) to detect the effects of Doll's decision rules on an actual scheduling situation, hence to discover factors for deriving fast delivery and high efficiency in customer services.

1.2 Research Approach

As in Doll's research, computer simulation is used as the research tool in this study. An actual business situation is simulated, schedules are developed and vehicles are dispatched to follow these schedules according to formal decision rules. The results of these simulation experiments are analyzed and compared to the summary statistics of the actual schedules used in the business situation.

Before setting up the experiments, information about the actual business situation must be available. They are:

(a) vehicle fleet information: this includes simulation of the total number and size of vehicles available on each day;

(b) information on certain limitations such as working hours of each of the days being simulated, and some service time coefficients;

(c) information on the set of customers such as arrival time of each customer requirement, together with its location and quantity.

A computer simulation model is developed using the above information.

Different sets of experiments are established to investigate different solution methods. These solution methods are generated by means of taking different scheduling heuristics with various parameter values for each of the dispatching decision rule parameters contained in Doll's scheduling decision rules and dispatching decision rules. Included also are different ways of sectoring in dispatching vehicles to follow the schedules developed.

In each of the experiments , statistics such as mean travel time per customer, mean and standard deviation of time to serve a customer and mean and standard deviation of delivery time per customer will be collected and compared to the corresponding statistics of the schedules actually implementd in the business situation. Here, the time to serve a customer includes the travel time and unloading time to serve this customer, and the delivery time per customer is defined as the time between the arrival of customer demand and the completion of service.

The concluding chapter will discuss the results of the above comparison. This evaluates the performance of the decision rules in the actual business situation. Additional areas of investigation are discovered as side results of the experiments.

CHAPTER II

REVIEW OF DOLL'S WORK

This chapter is divided into three sections. The first section gives a formal definition of the vehicle-scheduling problem, the research problem. The second section involves a detailed explanation of Doll's decision rules upon which this research is based. The last section is a summary of Doll's experiments and results on his hypothetical case.

2.1 The Vehicle-Scheduling Problem

A vehicle-scheduling problem can be stated as follows:

To develop schedules and following these schedules, dispatch vehicles of known capacity to serve a set of customers, each at a known location and with a known requirement for some commodity, subject to the constraints that:

(a) the requirements of all the customers must be met;

(b) the total load allocated to each vehicle may not exceed its capacity;

(c) the total time for each vehicle to complete its tour may not exceed some predetermined level.

The objective of the solution is the minimization of the total cost of delivery. This cost may be the sum of costs associated with the fleet size and the costs of completing the delivery tours.

Since most of the relevant factors in vehicle-scheduling (such as the location of customers, customer requirements, the number of vehicles and the size of vehicles) do change with time , the problem is often dynamic. The present research will therefore address itself to such dynamic vehicle-scheduling problems.

In solving a dynamic vehicle-scheduling problem, two decisions are involved:

(a) that of developing schedules;

(b) that of when to dispatch.

Decisions are made to achieve the objective of maximizing profits by accounting for both vehicle cost efficiency and customer service quality. Doll has developed two sets of decision rules, one for scheduling and the other for the dispatch of vehicles. These rules will be summarized as follows.

2.2 Doll's Decision Rules

2.2.1 Scheduling Decision Rules

A schedule is an ordered set expressed in the form ($D-S_1-$

S_2- ... -S_{n_k}-D) where D denotes the depot and S_1, S_2, ..., S_{n_k} denote the n_k customers served in this schedule. When constructing a schedule by any of the heuristics described below, the feasibility conditions must be checked. These conditions are that a schedule is feasible if the sum of the customer requirements on the schedule is less than the vehicle capacity and if the time required by the schedule is less than the time remaining in the day.

Doll's scheduling decision rules contain the time saved heuristic and the closest customer heuristic. Reasons for selecting these two heuristics and the pertinent literature review are given in Doll's thesis[10].

2.2.1 (1) Closest Customer Heuristic (C.C.H.)

This heuristic was developed by O'Neil[20] and adopted by Doll. For this decision heuristic, the first customer selected is the one closest to the depot and the subsequent customers selected are those closest to the last selected customer. This heuristic requires the following information:

(a) the number of vehicles available;

(b) the capacity of the vehicles;

(c) the current time;

(d) the end of day time;

(e) the number of customers;

(f) the location of customers in relation to the depot; and to each other;

(g) the requirements of the customers.

The functioning of this heuristic is a repetitive process. First the customer closest to the depot is added to the schedule and it is tested for feasibility. If it is not feasible, the next closest customer demand is tried until a customer is found which is a feasible addition to the schedule, or until all customers have been tried. If it is feasible, then the customer closest to the customer just added to the schedule, is next added to the schedule and the new schedule is tested for feasibility. The same procedure is repeated until no more customer can be added to the schedule because of limitations set by vehicle capacity and/or the time remaining in the day. If another vehicle is available and customer demands remain to be serviced, this scheduling process will be repeated for the next vehicle.

2.2.1(2) Travel Time Saved Heuristic (T.S.H.)

Another scheduling heuristic of Doll's was first introduced by Dantzig and Ramser[9] as a part of a linear programming formulation of the travelling salesman problem. It was subsequently improved and removed from the linear programming context by Clarke and Wright[7]. This heuristic begins with the assumption that all customers are on separate schedules including only one customers. This schedule takes the form (D-S_i-D) where S_i denotes the i-th customer on the schedule. Then customers are included on a common schedule based on the amount of scheduled travel time saved by their inclusion. This is done by arranging in descending order the travel time saved, which is the time difference between serving two customers separately from the depot and serving them sequentially on the same schedule. This heuristic requires the same information listed in 2.2.1(1) in addition to the computation of a travel time saved matrix.

If $D_{o,i}$, $D_{i,j}$ and $D_{j,o}$ denote the travel times between the depot and customer i, between customer i and j, between customer j and the depot respectively, then, the time required to serve customer i and j separately is $2D_{o,i}+2D_{j,o}$, the time required to serve them in one schedule is $D_{o,i}+D_{i,j}+D_{j,o}$. Hence, the time saved is $(2D_{o,i}+2D_{j,o}) - (D_{o,i}+D_{i,j}+D_{j,o})$, or $D_{o,i}-D_{i,j}+D_{j,o}$, where the distance matrix is assumed to be symmetrical.

After calculating the time saved matrix, this heuristic proceeds repetitively as follows. The pair of customers with the largest time saved value is included in a schedule, provided that all feasibility conditions stated above are satisfied. If the schedule is not feasible, the time saved value of this pair of customers is removed from further consideration, and the remaining pairs of customers are considered by following the previous procedure. After the initial pair of customers is selected, the time saved matrix is searched to add another customer to the beginning or the end of the schedule. This new customer is selected on the basis of largest time saved when combined with the first customer or the last customer on the schedule and the selection should not violate the feasibility conditions. This procedure is repeated until no more customers or vehicles are available.

After schedules are formulated, the next decision is on the dispatch of vehicles. An application of dispatching decision rules determines when a vehicle should be dispatched to follow a schedule. These rules affect the customer service criteria directly and they affect the travel time of the vehicles indirectly. Before a vehicle can be dispatched , the following conditions must be satisfied:

(a) at least one customer demand exists to be served;

(b) at least one vehicle is available for dispatching;

(c) at least one schedule exists that can be completed by the end of the current day.

When the above conditions are satisfied, Doll's decision rules can be applied to the dispatching of vehicles. His rules are as follows.

2.2.2 Dispatching Decision Rules

Rule 1: DISPATCH IF $EI_K \leq ME$

This rule requires that the schedules to be followed attains a minimum level of efficiency ME before a vehicle is dispatched.

Here, the efficiency index, EI_K, is defined as the schedule time per customer served in schedule K. The maximum efficiency index, ME, is a decision rule parameter, the numerical value of which is pre-defined. The imposition of a maximum limit on EI_K will ensure that the total daily travel time does not exceed some maximum value.

Rule 2: DISPATCH VEHICLES IF $B > MB$

This rule requires that more than some specified minimum number of customer demands have been received before a vehicle is dispatched.

Here, B, the current backlog, generates the delay in serving an order. Parameter MB, the minimum backlog, is the decision rule parameter which, with a pre-defined value, controls the functioning of this decision rule condition.

Under this rule, the servicing of customer demands is often delayed until there is a sufficiently large number of customers awaiting service. This rule will increase the efficiency of the schedule but the mean service time per customer is expected to increase as travel time per customer is decreased.

Rule 3: ONLY WHEN ONE OR MORE VEHICLES ARE DISPATCHED IS THE NEXT SECTOR CONSIDERED.

This rule requires that a vehicle or vehicles must be dispatched within the geographic sector of customer locations currently being considered.

The geographical sectors can be defined as dividing a square or circular region into S equal segments, or subdividing the whole region into S irregular subregions according to the density of customer requirements. To apply this decision rule, consider firstly the customers in sector number one. Vehicles are dispatched to these customers if the dispatching feasibility conditions are met. After vehicles are dispatched to serve customer requirements in sector one, the customer requests in sector two will be considered. The process continues until at least one vehicle is dispatched to all S sectors, then it starts again in sector number one.

As expected, the within sector condition increases mean service time because of the delays of customer requests in sectors not currently being considered, but it decreases travel time because of the increase in customer requests density.

The three decision rules listed above will require a knowledge of three parameters:

(a) the maximum efficiency index, ME;

(b) the minimum backlog per sector, MB;

(c) the number of sectors, S.

It is possible to eliminate one or more of the constraints in the three decision rules by assigning different numerical values to their associated parameters. For instance, to allow vehicles to be dispatched without a consideration of the efficiency level, ME can be set to some large numerical value. To eliminate any backlog, a value of zero can be applied to MB, and by setting the number of sectors S to one, the sectoring constraint will be eliminated.

2.3 Summary of Doll's Experiments and Results

To evaluate the scheduling and the dispatching decision rules, Doll designed a set of simulation experiments defined with different customer request rates. At a given customer request rate, customer demands were generated according to a negative exponential probability distribution with uniformly distributed units of requirements. In each of these problems, the location of each customer was represented by a grid point on a coordinate plane with the depot as the origin. They scattered on the plane following a given probability distribution function. Assumptions were also made on loading and unloading time, initial number of vehicles and their capacity.

In each of the experiments performed, schedules were developed and vehicles were dispatched to follow these schedules according to different solution methods to solve one of the hypothetical problems defined. These solution methods were generated from Doll's decision rules by using one of the two scheduling heuristics with the other factors held constant, or using different values of the dispatching rule parameters with the other factors held constant, or imposing all dispatching conditions at the same time. The mean travel time per customer, the mean time to serve a customer and the standard deviation of the time to serve a customer were collected as simulaton output and in each experiment, they were used to measure the effectiveness of the solution methods. These three performance measures are used because the mean travel time per customer is directly related to the operating cost of the vehicle fleet; the mean time to serve a customer is a measure of service quality; and the standard deviation of the time to serve a customer is a measure of the reliability of service.

Analysis of Doll's experiments can be summarized as follows:

(a) The time saved heuristic always has less mean travel time per customer than the closest customer heuristic. Also, the time saved heuristic produces a lower value of standard deviation of the time to serve a customer. However, the closest customer heuristic provides consistently lower mean time to serve a customer.

(b) The dispatching decision rules have relatively little effect on the travel time per customer. Increasing the maximum efficiency parameter results in the largest reduction of travel time per customer and also in the largest increase of the mean and the standard deviation of the time to serve a customer. Increasing the number of sectors results in a reduction of the mean and the standard deviation of the time required to serve a customer, but it has virtually no effect on mean travel time. In general, as mean travel time per customer decreases, there is an increase in the mean and the standard deviation of the time required to serve a customer. However, combinations of dispatching rule parameters (with both the ME and MB parameters functioning) result in reducing mean travel time and mean service time below the expected values. It was noted that the maximum efficiency parameter, ME, causes a large increase in the standard deviation of service time in some circumstances. This causes an unacceptable maximum service time.

(c) Two effects of different customer request rates on the performance of the decision rules were discovered. Firstly, as the customer request rate increases toward the maximum capacity of the vehicle fleet, the performance of different decision rules converges toward the same mean travel time per customer and mean service time per customer, and some decision rules produce a service rate less than the customer request rate and thus saturate the fleet at high customer request rates. Secondly, at the maximum customer request rate, the closest customer heuristic should not be used because it results in excessive delays for customers far from the depot.

The following recommendations were offered by Doll for possible application of his decision rules:

(a) If minimizing mean travel time is important, use the time saved heuristic and a high value for the backlog parameter.

(b) If minimizing mean service time is important, use the closest customer heuristic and a sectoring dispatching rule, unless the fleet is operating near saturation. In this case, the time saved heuristic should be used.

(c) For a given operating situation, it is possible to improve operations by, say, reducing backlog and adding sectoring to improve mean service time while maintaining a satisfactory mean travel time.

CHAPTER III

METHOD OF ANALYSIS

In this chapter, an actual business situation is presented and the computer simulation model is described together with a comparison of the differences between these two systems.

3.1 Data Source

ALLTRANS EXPRESS LTD. (Vancouver) provided an actual business situation requiring the solution of a dynamic vehicle-scheduling problem. ALLTRANS was selected because it has a large volume of delivery services and the company made its data readily available for this research.

Following is a description of the delivery services offered by ALLTRANS to its customers.

Daily customer requests are dynamic in nature. Dispatchers develop schedules and following these schedules, vehicles are dispatched as soon as possible to serve existing customer requests. Usually, one third of the customer requests handeled on a given day were received during the working hours of the previous day, and the remaining requests were received after the working hours of the previous day. In developing a schedule, factors such as customer location, arrival time and the amount to be delivered are considered. The loading limit of each delivery truck is 550 cubic feet. The Vancouver area has been sectored as shown in FIGURE III.1 . Usually, customers located in the same sector will be included in the same schedule until no more load can be put on this truck, and another schedule will be developed to serve the remaining customers. On the other hand, if loading limit is not reached after loading for all customers located in a specified sector, customers in nearby sectors will be added to the schedule.

Each of the delivery trucks is loaded after mid-night, and is ready to leave the depot immediately after the driver obtains the work order from the dispatcher on the following day. This therefore excludes the loading time from the schedule time.

Drivers report to work at the depot at 8:30 a.m. and finish work at approximately 3:30 p.m. each day, having a coffee break in the morning and a lunch break at noon time. Usually, a driver can only finish two schedules a day at most, one in the morning and one in the afternoon.

A sample of actual schedules obtained from the records of ALLTRANS is presented as APPENDIX I. This sample contains scheduling and dispatching information for six days. In these schedules, 201 customers located in the central area of Vancouver City with varying demand volumes were served. A number of delivery trucks were dispatched according to schedules developed by the company. Customer information from the ALLTRANS records included:

(a) location of a customer;

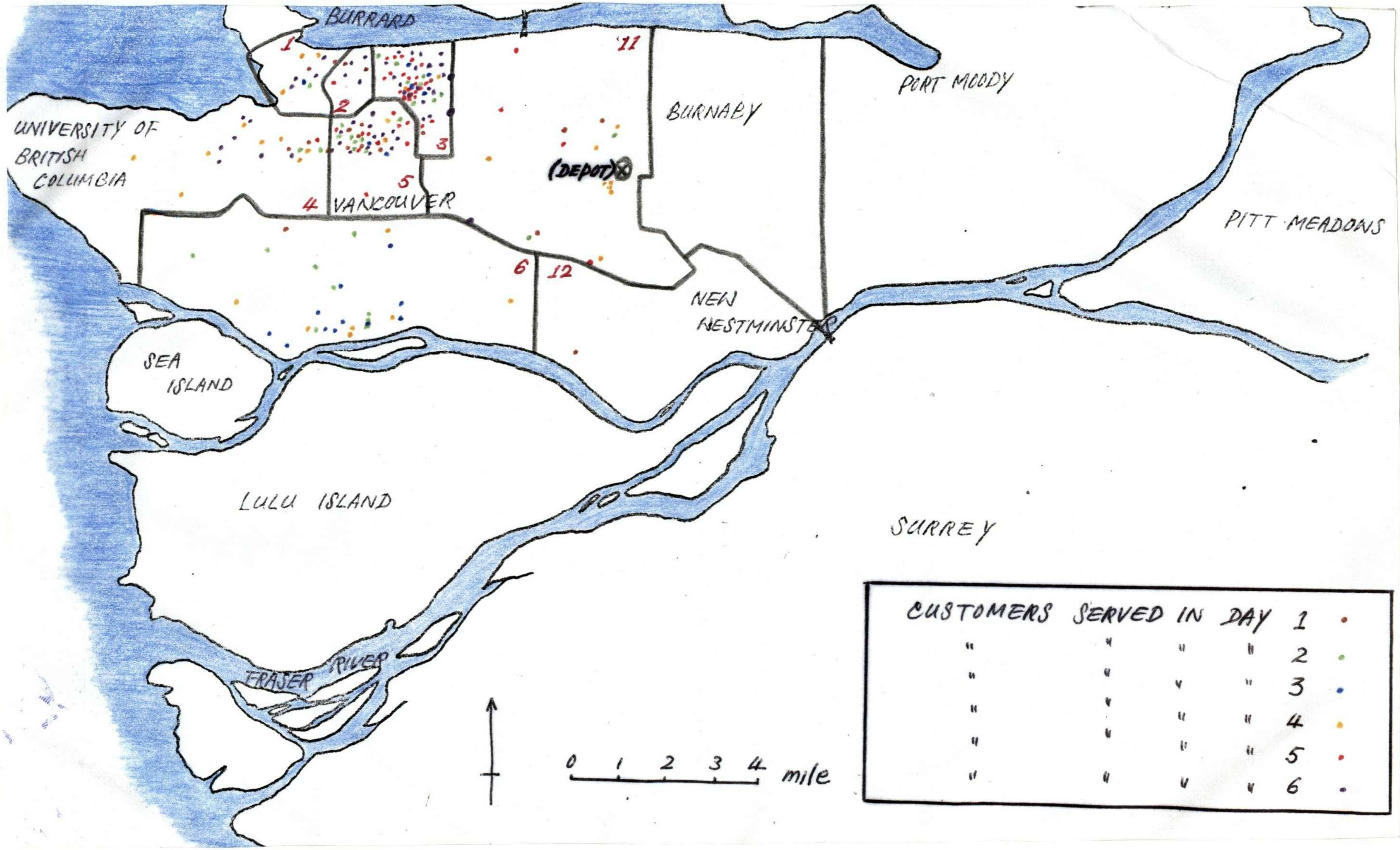

FIGURE III.1 ALLTRANS' SECTORING OF CITY VANCOUVER AND LOCATION OF CUSTOMERS ON RECORDS

(b) amount of customer demand, in terms of weight;

(c) for each truck, arrival time at and departure time from the location of a customer, (hence the traveling time from one location to another and the unloading time at each location).

However, the arrival time of a customer request is not included in these records.

The above raw information was converted into a suitable form for a simulation model which is presented in section 3.3 .

3.2 Source Data Modification

Several data modifications were implemented to enable a comparison of computer simulated results with the vehicle-scheduling solutions of ALLTRANS. These modifications are:

(a) The number of simulation days is taken as six. With the exclusion of coffee and lunch time, drivers are supposed to work five hours a day.

(b) Unloading time for each customer is taken as 10 minutes which is the mean unloading time derived from the sample supplied by ALLTRANS. For reasons given in the first section of this chapter, loading time is not included in a schedule.

(c) Amounts of customer demands recorded in terms of weight have been converted into volume. This is done by assuming that all commodities delivered by one truck in any given schedule have the same density together with the fact that each delivery truck is at least 98 per cent fully loaded. Information on the percentage loading of trucks has been supplied by dispatchers of ALLTRANS.

(d) The time at which customer demands occur has not been recorded. In order to compare the efficiency in customer service, occurance times of customer demands which are served on the same day by ALLTRANS are assumed to arrive at the beginning of the day.

(e) From the given records, travel time information can only be obtained for certain pairs of locations. In the simulation model, travel time is estimated by an empirical equation derived for the Greater Vancouver Region.

$$TT = 3.85+0.00313(x+y)+0.0106(HYPO)-2.4(HYPO)^2$$

where

TT is the travel time in units of minutes;

$HYPO = (x^2+y^2)^{1/2}$;

$(HYPO)^2 = (x^2+y^2)\cdot 10^{-6}$;

x and y are the x-coordinate and y-coordinate of the location point on a Vancouver map, with the depot as the origin (0,0).

Scale for x and y is 240 graphic units to one mile.

50 sample location points were picked to test the reliability of this travel time estimation equation. Travel time between each pair of consecutive points was obtained from the supplied records. There was significant correlation between the actual travel time and the estimated travel time. (Correlation coefficient is 0.837 with 50 degrees of freedom.) this shows that the model is reliable.

3.3 Input Data

Customer information input extracted from ALLTRANS records is given in APPENDIX I. These records contain information on 201 customer requirements, in 28 schedules, and for a period of six days. These 201 customer requirements came from 90 different customers, one of them requested service five times, another one requested service three times, and another five requested service twice within these six days. The number of customers served per day ranges from 17 to 57. Per schedule information obtained from analyzing the 28 schedules recorded is given in TABLE III.1. In this table, (1) the number of customers served in a schedule is defined as the number of customers contained in a schedule; (2) schedule time per customer served in a schedule is defined as the average service time (including travel time and unloading time); and (3) unloading time per customer is defined as the unloading time at each customer location.

According to the above results, and in order to develop at

TABLE III.1 ANALYTICAL RESULTS OF DATA SUPPLIED BY ALLTRANS

	RANGE	MEAN	STAND.DEV.
(1) NO. OF CUST. SERVED IN A SCHED.	1-20	7	4
*(2) SCHED.TIME PER CUST. SERVED IN A SCHED.	14-34	21	10
(3) UNLOADING TIME PER CUST.	1-30	9	4

TIME MEASURED IN MINUTES.

* IN THE GIVEN SAMPLE, THE SERVICE TIME FOR ONE CUST. IS 60 MINUTES. THIS HAS BEEN CONSIDERED AS AN EXCEPTIONAL CASE, HENCE THE CUST.IS EXCLUDED IN DERIVING MEAN AND STANDARD DEVIATION OF THIS TIME.

least one schedule in every simulation day, values of decision rule parameters are set as given in TABLE III.2 based on Doll's decision rules.

3.4 Computer Simulation Model

In this research, the scheduling situation posed above is solved with a numerical simulation model using Doll's decision rules. As simulation is a method of symbolically representing a real situation, any number of solution methods can be applied to the problem. The model used in this research is a modification of Doll's.

Doll's simulation program, written in the computer simulation language called GASP[21], contains the following parts:

(a) generation of the input stream, e.g. the arrival of customer demands, by means of a random number generator according to the probability distribution functions defined;

(b) application of the decision rules to the scheduling and dispatching decisions;

(c) collection of statistics on the simulation results.

To accomodate the research problem under study, part (a) of Doll's program was replaced by a sub-program which reads in collected information about customer demands, but part (b) and part (c) remain unchanged. This simulation program is event

TABLE III.2 RANGE OF PARAMETER VALUES IN THE EXPERIMENTS DESIGNED

	RANGE
ME	20-30
MB	0-17
*S	1-17

* THE DECISION RULE OF SECTORING DEPENDS ON SECTORING MECHANISM RATHER THAN VALUES OF PARAMETER S. DIFFERENT SECTORING MECHANISM ARE DESCRIBED IN SECTION 3.5 OF THIS CHAPTER.

oriented which means that simulation time is counted from event to event, ignoring model action between events.

There are six basic types of events in this simulation model:

(a) an initialization event,

(b) a vehicle available event,

(c) a customer occurrence event,

(d) an end of day event,

(e) the end of simulation event,

(f) a change of sectoring event.

The initialization event initiates the simulation by initializing the programmer defined variables as well as the necessary GASP variables. Customer information for the day is read in (SUBROUTINE REDATA).

If a vehicle available event occurs, the vehicle available list is updated (SUBROUTINE VEHUP) and the lists of available vehicles are put in working arrays for use by the decision rule process (SUBROUTINE VEHCUS). If a customer occurrence event occurs, the customer available list is updated (SUBROUTINE CUSUP) and the lists of available customers and available vehicles are put in working arrays for use by the decision rule process (SUBROUTINE VEHCUS). Schedules are then formulated according to the decision rules (SUBROUTINE DECRUL). The vehicles assigned to the schedules are removed from the vehicle available lists. A vehicle available event is generated when the schedule ends. Similarly, the customers assigned to the schedules are also removed from the customer available lists. The sectoring mechanism is invoked when a change of sectoring event occurs (SUBROUTINE VEHCUS). Details on the sectoring mechanism are given in section 3.5 . For each schedule developed, the per schedule statistics are recorded (SUBROUTINE UPDATE).

When an end of day event occurs, daily statistics are recorded (SUBROUTINE ENDAY). The lists of available customers and available vehicles are stored in working arrays to be used in the next day by the decision rule process (SUBROUTINE VEHCUS).

The end of simulation event terminates further simulation. The program then computes the final statistics which are subsequented printed (SUBROUTINE ENDSIM).

FIGURE III.2 is a macro flow chart of this simulation.

3.5 Experimental Design

Details on the design of each set of experiments are given in this section. This includes: (a) scheduling heuristic used; (b) values assigned to the dispatching decision rule parameters; and (c) methods of sectoring.

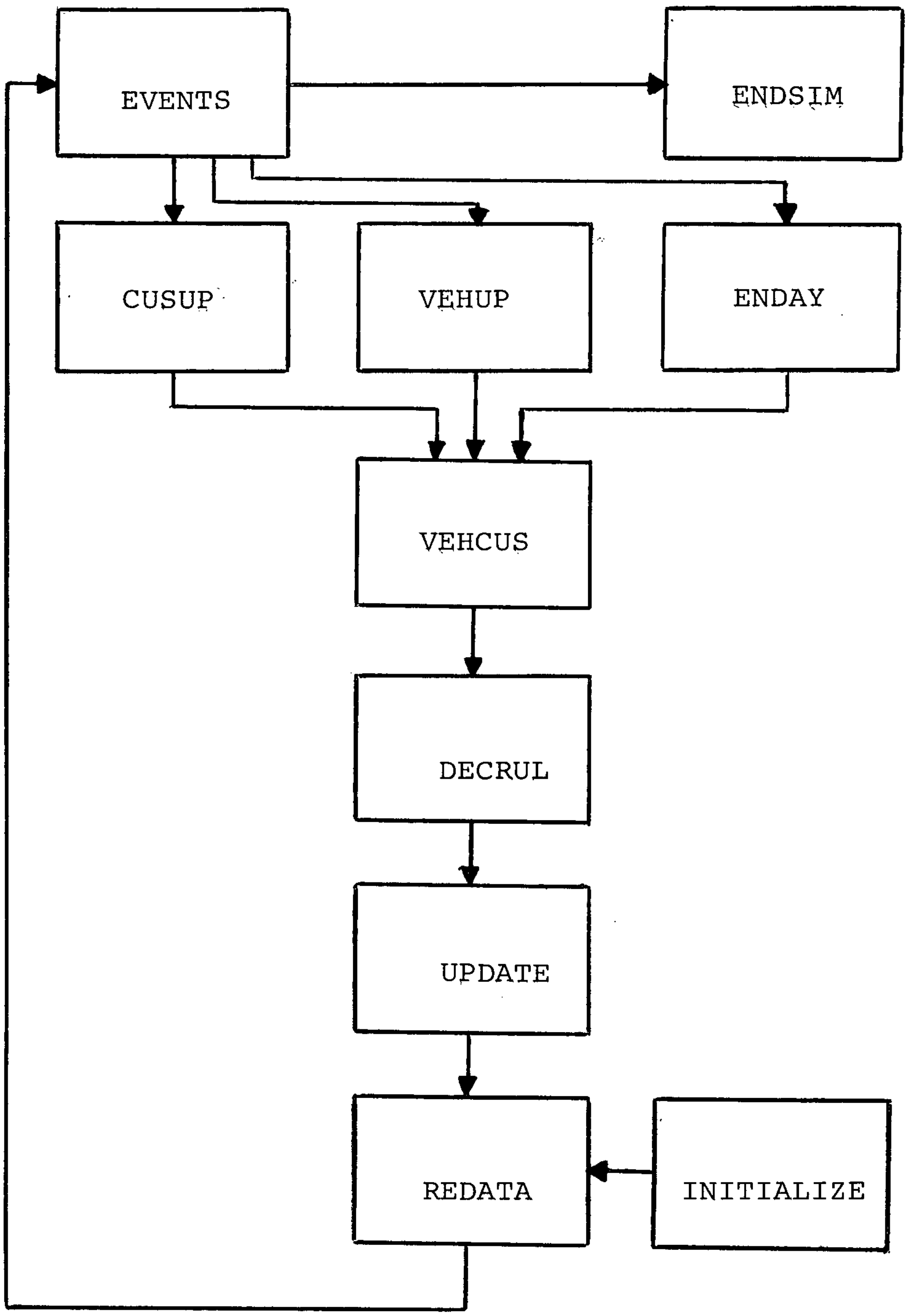

FIGURE III.2 MACRO FLOW CHART OF THE SIMULATION MODEL

Four sets of experiments are designed for this study.

SET A. This set of experiments attempts to test the effect of using different values for MB. In these experiments, scheduling decision rules being tested include C.C.H. and T.S.H.. For each of these heuristics , parameter values for ME and S are fixed as 10000 and 1 respectively to avoid any influence from the two associated decision rule conditions. The parameter value of MB varied within the range from 0 to 17, a range which is realistic in terms of source data and an understanding of Doll's decision rules. These experiments are listed in TABLE III.3.

SET B. This set of experiments is designed to test the effect of using different values for ME. This set of experiments is similar to SET A, but the parameter of ME is allowed to vary while MB is fixed at 0. The range of ME is set between 20 and 30. Experiments are listed in TABLE III.4.

SET C. This set of experiments is designed to test the effect of using scheduling decision rules with different sectoring mechanisms. As in SET A and SET B, both scheduling heuristics are tested, and parameter values of ME and MB are fixed respectively as 10000 and 0 to preclude their influence. Sectoring mechanisms considered in these experiments include:

S(1) The entire area is considered as one sector. (These experiments are identical to two experiments in SET A and SET B, hence are not duplicated.)

TABLE III.3 LISTING OF EXPERIMENTS IN SET A

EXP. NO.	SCHED.DECISION RULE	DISPATCHING RULE PARAMETER		
		S	ME	MB
(1)	CLOSEST CUST. HEURISTIS	1	10000	0
(2)	CLOSEST CUST. HEURISTIC	1	10000	5
(3)	CLOSEST CUST. HEURISTIC	1	10000	10
(4)	CLOSEST CUST. HEURISTIC	1	10000	15
(5)	TIME SAVED HEURISTIC	1	10000	0
(6)	TIME SAVED HEURISTIC	1	10000	5
(7)	TIME SAVED HEURISTIC	1	10000	10
(8)	TIME SAVED HEURISTIC	1	10000	15

* DIFFERENT SECTORING MECHANISM USED ARE DESCRIBED IN THE CONTENT OF EXPERIMENTAL DESIGNED.

TABLE III.4 LISTING OF EXPERIMENTS IN SET B

EXP. NO.	SCHED.DECISION RULE	DISPATCHING RULE PARAMETER		
		S	ME	MB
(1)	CLOSEST CUST. HEURISTIS	1	30	0
(2)	CLOSEST CUST. HEURISTIC	1	25	0
(3)	CLOSEST CUST. HEURISTIC	1	23	0
(4)	CLOSEST CUST. HEURISTIC	1	21	0
(5)	TIME SAVED HEURISTIC	1	30	0
(6)	TIME SAVED HEURISTIC	1	25	0
(7)	TIME SAVED HEURISTIC	1	23	0
(8)	TIME SAVED HEURISTIC	1	21	0

* DIFFERENT SECTORING MECHANISM USED ARE DESCRIBED IN THE CONTENT OF EXPERIMENTAL DESIGNED.

S (2) The entire area is divided into two sectors which coincide with the second and third coordinate quadrants shown in FIGURE_III.3.

S (3) ALLTRANS sectoring scheme is followed (FIGURE III.4).

S (4) Based on the algorithm developed by Christofides[5], a new sectoring mechanism was developed as follows:

Subdivide the whole area into elementary squares of 200x200 graphic units. (This size was derived from the clustering of customer demands.) All customers being served in the same day within the same elementary square are considered as one aggregated-customer where the demand of the aggregated-customer is equal to the sum of the demands of those customers. Using historical data , fuse some elementary squares together as follows: minimize the area of the region of fused elementary squares such that the total area demand of the region does not exceed the loading limit of each delivery truck , and the elementary squares have more than a single corner point in common. Area demand of each elementary square is taken as the maximum value of the demands of the aggregated-customers in the square.

The subregions of the simulated area developed by this sectoring mechanism is given in FIGURE_III.5 .

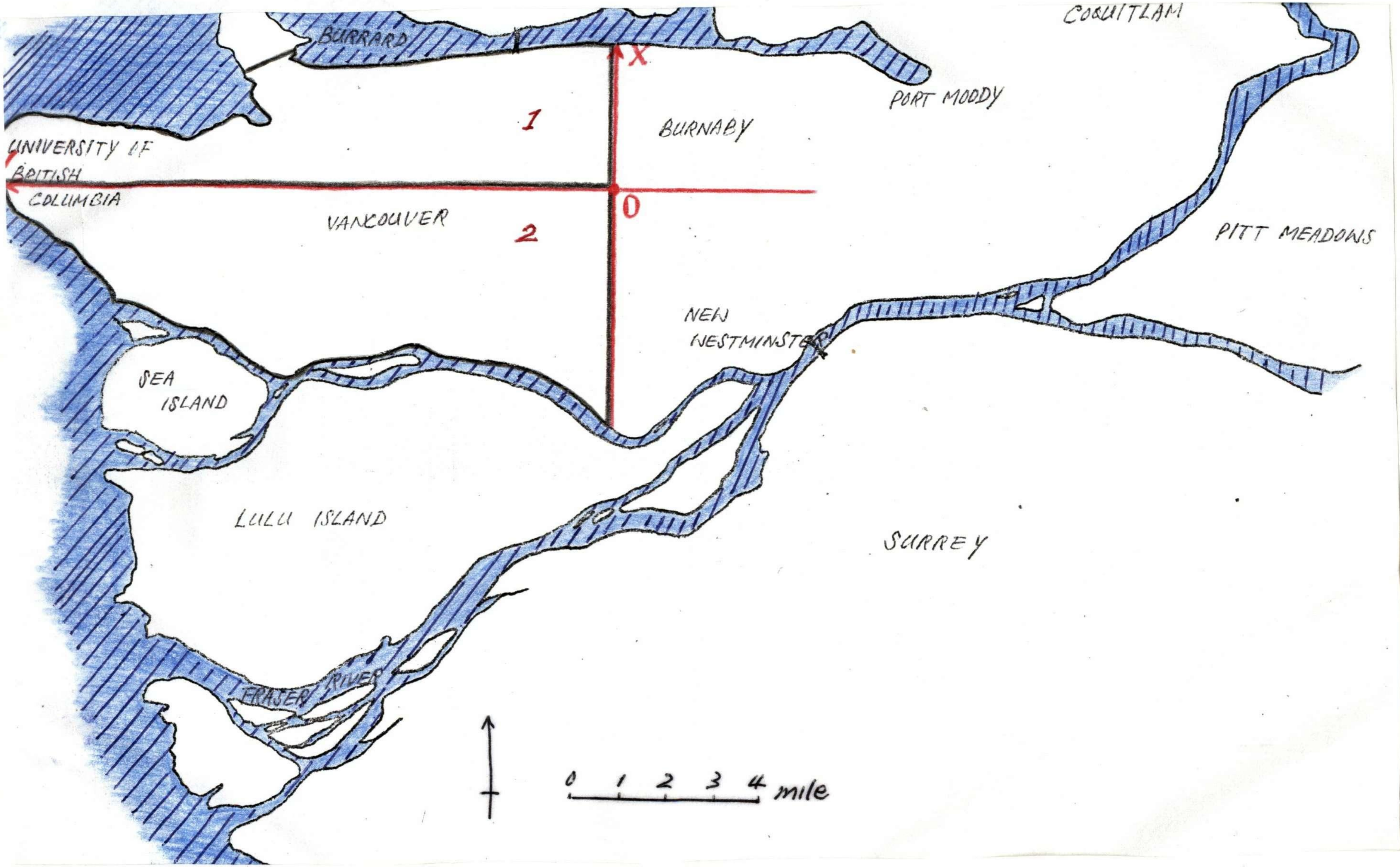

FIGURE III.3 SECTORING OF THE SIMULATED AREA BY SECTORING MECHANISM S(2)

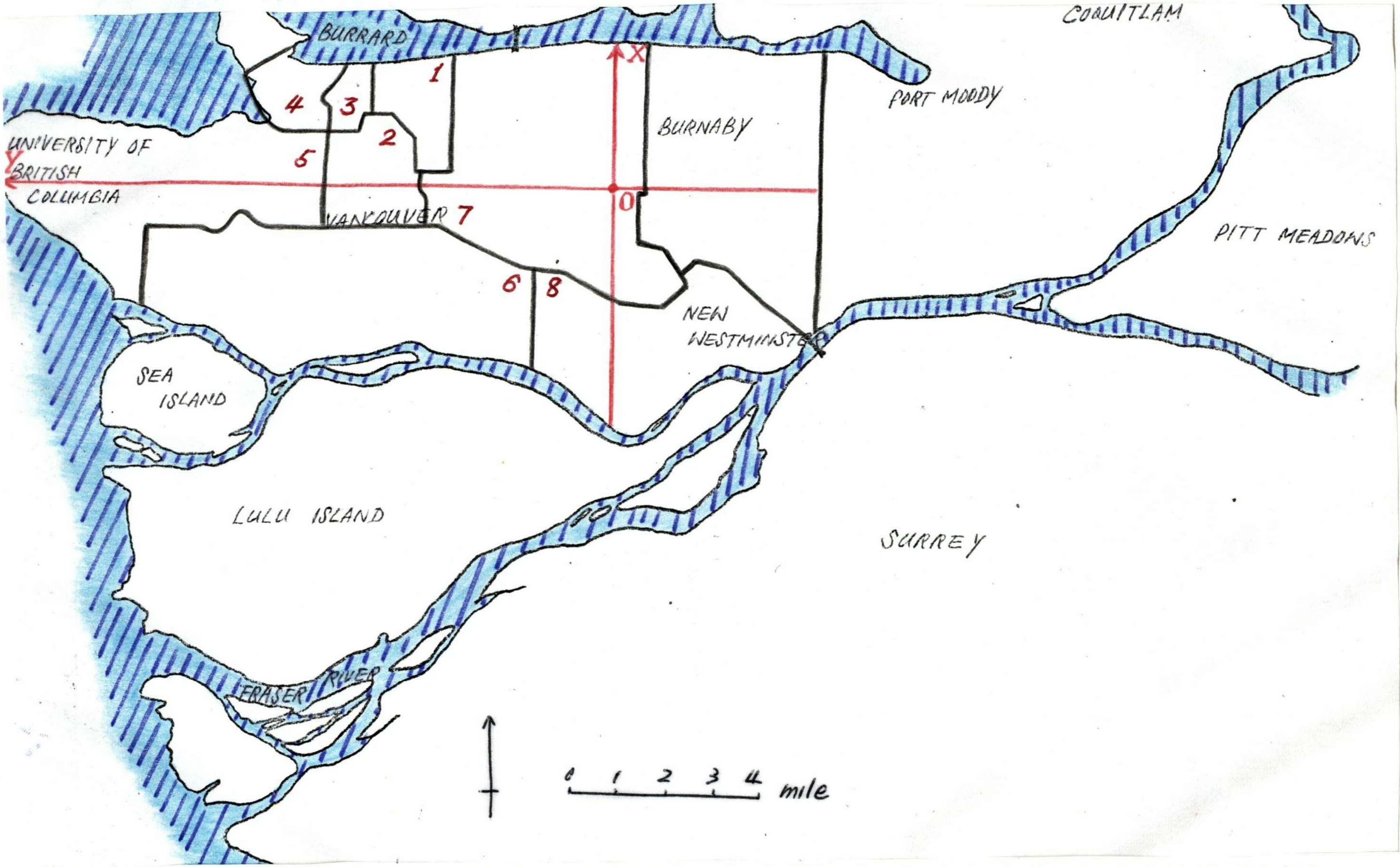

FIGURE III.4 SECTORING OF THE SIMULATED AREA BY SECTORING MECHANISM S(3)

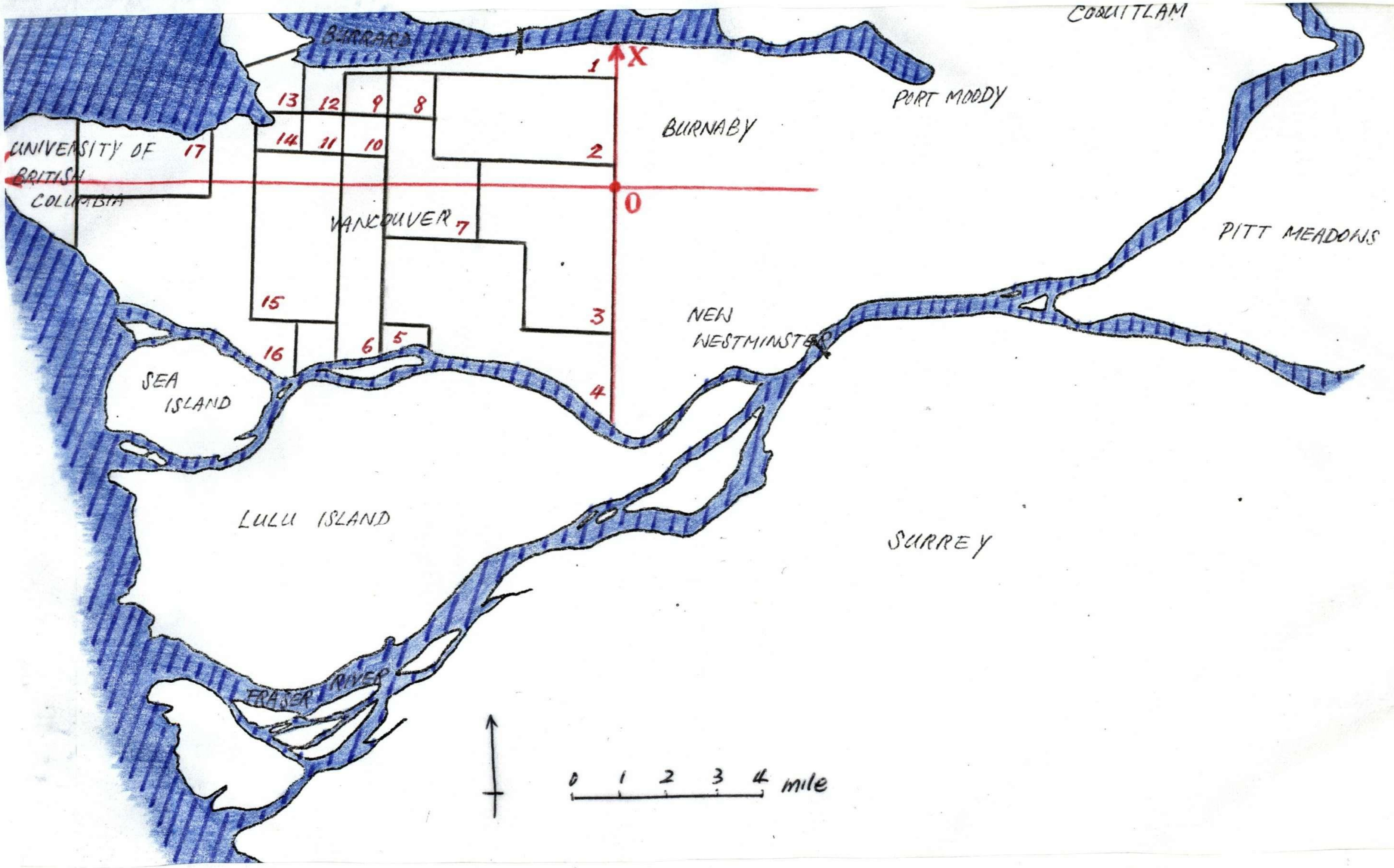

FIGURE III.5 SECTORING OF THE SIMULATED AREA BY SECTORING MECHANISM S(4)

TABLE III.5 LISTING OF EXPERIMENTS IN SET C

EXP. NO.	SCHED.DECISION RULE	DISPATCHING RULE PARAMETER		
		*SECT.MECH.	ME	MB
(1)	CLOSEST CUST. HEURISTIS	S(1)	10000	0
(2)	CLOSEST CUST. HEURISTIC	S(2)	10000	0
(3)	CLOSEST CUST. HEURISTIC	S(3)	10000	0
(4)	CLOSEST CUST. HEURISTIC	S(4)	10000	0
(5)	TIME SAVED HEURISTIC	S(1)	10000	0
(6)	TIME SAVED HEURISTIC	S(2)	10000	0
(7)	TIME SAVED HEURISTIC	S(3)	10000	0
(8)	TIME SAVED HEURISTIC	S(4)	10000	0

* DIFFERENT SECTORING MECHANISM USED ARE DESCRIBED IN THE CONTENT OF EXPERIMENTAL DESIGNED.

TABLE_III.5 lists the experiments in SET_C .

SET_D. This set of experiments attempts to test the effect of all decision rules combined. Experiments in this set are taken as "combinations" or "modifications" of experiments contained in SETs A, B and C. By "combinations", it is meant that the experiments are designed by varying the scheduling decision rules and the parameter values for ME, MB and S at the same time. By "modifications", it is meant that some procedures in an experiment are changed. For example, the length of a working day is extended, or the decision rule process is varied. The following miscellaneous experiments were performed:

(1) Extend the working time limit of each simulation day to 600 minutes to ensure same-day service. The scheduling heuristic used was C.C.H.. Parameter values for ME, MB and S are 10000, 0 and 1 respectively.

(2) Similar to (1) except that the scheduling heuristic used was T.S.H instead.

(3) In the application of sectoring mechanism S(3) (ALLTRANS mechanism), modify that part of the dispatching decision rule concerning the within sector condition as follows:

THE NEXT SECTOR IS CONSIDERED IF VEHICLE DISPATCHING IS NOT POSSIBLE IN THE SECTOR BEING CONSIDERED UNDER THE PREDEFINED DISPATCHING DECISION

RULE CONDITIONS, EVEN IF NO VEHICLE HAS BEEN DISPATCHED IN THIS SECTOR.

Use C.C.H., with ME and MB being 10000 and 0 respectively. This is simply a modified experiment of experiment (3) in SET C, used to detect the effect of sectoring mechanism S(3) in conjunction with the other parts of the decision rules.

(4) As in (3) but using T.S.H., this is a modified experiment of experiment (7) in SET C.

(5) and (6)

In order to test the effect of over-all application of Doll's decision rules, these two experiments apply C.C.H. and T.S.H., respectively, with ME=50, MB=0 and using sectoring mechanism S(4).

(7) and (8)

Similar to (5) and (6), these two experiments are designed to test the effects of combining conditions of the dispatching decision rules. C.C.H. was used in (7) and T.S.H. was used in (8). ME was set at 25 while MB was set at 5 with sectoring mechanism S(1) active.

3.6 Output Data

For each experiment performed, five performance measures are collected from the simulated results:

(a) mean travel time per customer;

(b) mean service time per customer, where service time is the sum of travel time and unloading time;

(c) standard deviation of service time per customer;

(d) mean delivery time per customer, where delivery time is defined as the time between the receipt of a customer demand and the completion of service;

(e) standard deviation of delivery time per customer.

These five measurements are basic components of a profit function which is here unknown. However, in order to achieve the objective of this study, it is sufficient to test the effectiveness of the decision rule methods based on these measurements. Travel time per customer and the mean service time per customer are the short term variable costs of operating the vehicles. The standard deviation of service time per customer reveals the reliability of estimating vehicle operation cost based on the mean travel or service time per customer. Mean delivery time per customer measures the efficiency of customer services, and the standard deviation of delivery time per customer measures the reliability of service. In a competitive area, high service efficiency attracts customers which in tern increases profit.

CHAPTER IV

RESULTS AND ANALYSIS

In this chapter, the results of the computer simulation experiments will be discussed and the performance of the vehicle scheduling according to Doll's decision rules will be evaluated.

4.1 Statistics of Data Supplied by ALLTRANS

In order to compare the actual solutions of ALLTRANS and the decision rule solutions, the same statistics abstracted from the simulation program were extracted from the data supplied by ALLTRANS . These are:

(a) mean travel time per customer;

(b) mean service time per customer;

(c) standard deviation of service time per customer;

(d) mean delivery time per customer;

(e) standard deviation of delivery time per customer.

TABLE IV.1 summarizes the above statistics.

4.2 Comparison of Actual and Simulated Data

Mean travel time per customer, mean and standard deviation of service time per customer, mean and standard deviation of delivery time per customer obtained from the simulated data provided by the simulation model are listed in TABLE IV.2 to TABLE IV.6. A comparison of the statistics taken on the actual and the simulated data shows the following:

(a) Mean travel time per customer for the formal decision rule solutions is not significantly different from that of ALLTRANS's solutions.

(b) Mean service time per customer request for the formal decision rule solutions is also found to be not significantly different from that of ALLTRANS's solutions. This follows from the result of insignificant difference in mean travel time per customer between the two solutions because service time is defined as the sum of travel time and unloading time, the latter having a fixed value of 10 minutes.

(c) Compared with ALLTRANS's solutions, over 78 per cent of the thirty-two simulation experiments performed, produced much smaller standard deviation of service time per customer. Where sectoring mechanism was operative, especially ALLTRANS mechanism (code S(3)), the measures of mean travel time per customer, mean

TABLE IV.1 STATISTICS OF DATA SUPPLIED BY ALLTRANS

	MEAN	STANDARD DEVIATION
TRAVEL TIME PER CUST.	12	-
SERVICE TIME PER CUST.	21	10
DELIV. TIME PER CUST.	151	106

TIME MEASURED IN MINUTES.

TABLE IV.2 RESULES OF EXPERIMENTS WITH APPLICATION OF CLOSEST CUSTOMER HEURISTIC

WITH S=1		TRAV.TIME PER DAY		TOT.NO. OF CUST. SERVED	TRAV. TIME PER CUST.	SERVICE TIME PER CUST.		DELIVERY TIME PER CUST.	
ME	MB	MEAN	S.D.			MEAN	S.D.	MEAN	S.D.
10000	0	729	176	189	13	23	6	132	70
10000	5	673	184	185	12	22	6	154	93
10000	10	643	218	179	11	21	7	179	130
10000	15	617	201	174	11	21	77	196	159
30	0	678	166	183	12	22	5	147	97
25	0	644	222	178	12	22	7	155	125
23	0	612	285	174	11	21	9	156	152
21	0	504	302	151	10	20	12	255	188

TIME MEASURED IN MINUTES.

TABLE IV.3 RESULES OF EXPERIMENTS WITH APPLICATION OF TIME SAVED HEURISTIC

WITH S=1		TRAV.TIME PER DAY		TOT.NO. OF CUST. SERVED	TRAV. TIME PER CUST.	SERVICE TIME PER CUST.		DELIVERY TIME PER CUST.	
ME	MB	MEAN	S.D.			MEAN	S.D.	MEAN	S.D.
10000	0	706	166	187	13	23	5	129	67
10000	5	660	169	185	11	21	5	140	86
10000	10	644	226	185	11	21	7	169	104
10000	15	626	202	179	11	21	7	194	116
30	0	677	171	185	12	22	5	141	84
25	0	667	217	186	11	21	7	142	88
23	0	574	243	168	10	20	9	204	178
21	0	575	229	171	10	20	8	175	166

TIME MEASURED IN MINUTES.

TABLE IV.4 RESULES OF DIFFERENT SECTORING MECHANISM WITH APPLICATION OF CLOSEST CUSTOMER HEURISTIC

WITH MB=0 ME=10000 SEC.MECH.	TRAV.TIME PER DAY		TOT.NO. OF CUST. SERVED	TRAV. TIME PER CUST.	SERVICE TIME PER CUST.		DELIVERY TIME PER CUST.	
	MEAN	S.D.			MEAN	S.D.	MEAN	S.D.
S(1)	729	176	189	13	23	6	132	70
S(2)	571	130	151	13	23	5	152	113
S(3)	93	228	19	19	29	72	101	59
S(4)	528	376	138	13	23	16	421	303

TIME MEASURED IN MINUTES.

TABLE IV.5 RESULES OF DIFFERENT SECTORING MECHANISM WITH APPLICATION OF TIME SAVED HEURISTIC

WITH MB=0 ME=10000 SEC.MECH.	TRAV.TIME PER DAY		TOT.NO. OF CUST. SERVED	TRAV. TIME PER CUST.	SERVICE TIME PER CUST.		DELIVERY TIME PER CUST.	
	MEAN	S.D.			MEAN	S.D.	MEAN	S.D.
S(1)	706	166	187	13	23	5	129	67
S(2)	573	131	153	12	22	5	156	114
S(3)	93	228	19	19	29	72	102	60
S(4)	515	369	133	13	23	17	418	294

TIME MEASURED IN MINUTES.

TABLE IV.6 RESULTS OF MISCELLANEOUS EXPERIMENTS CONTAINING IN SET D

EXP.NO.	TRAV.TIME PER DAY		TOT.NO. OF CUST. SERVED	TRAV. TIME PER CUST.	SERVICE TIME PER CUST.		DELIVERY TIME PER CUST.	
	MEAN	S.D.			MEAN	S.D.	MEAN	S.D.
(1)	766	230	201	13	23	7	144	82
(2)	744	220	201	12	22	6	139	83
(3)	752	155	178	15	25	5	148	80
(4)	760	162	181	15	25	5	146	75
(5)	528	376	138	13	23	16	421	303
(6)	515	369	133	13	23	17	418	294
(7)	645	248	180	11	21	8	159	140
(8)	663	207	185	11	21	7	152	94

TIME MEASURED IN MINUTES.

service time per customerand service time per customer standard deviation are large. Hence emphasis should be put on analyzing the design of the sectoring mechanism rather than the efficiency of the formal decision rule performance. Further discussion will follow in section 4.3.

(d) Mean delivery time per customer for the formal decision rule solutions ranges from 101 to 421 minutes, of which 44 per cent fell below the value of 151 which is the mean delivery time per customer from ALLTRANS's solutions. This shows that an application of the decision rules can in some cases result in higher service quality by reducing the time taken to satisfy customer demand.

However, the assumptions reguarding the receipt time of customer demands, as outlined in chapter III, must be kept in mind. The receipt time can only be assumed, making the validity of comparison questionable.

(e) The standard deviation of delivery time per customer of the formal decision rule solutions ranges from 59 to 303 minutes, and that of ALLTRANS's solutions is 105 minutes. As noted, the experiments which result in low mean delivery time per customer also result in low delivery time per customer standard deviation, suggesting that an application of the decision rules improves both the efficiency and the reliability of service. Further effects of the decision rules will be discussed in the next section.

In summary, the comparison of formal decision rule solutions and ALLTRANS's solutions does not indicate as great an improvement in solving the scheduling problem as expected. One notable point is that, in ALLTRANS' scheduling problem, there were many customers located near the boundary of the area to be served, and some of them are separated from other customer locations by relatively long distances. This characteristic in customer location led to the formulation of many decision rule based schedules containing only one customer. These schedules increase the mean travel time per customer to a value which can be rather large. Detailed discussion on this point is given in the last section of this chapter.

4.3 Performance of Doll's Decision Rules in the Problem

The thirty-two experiments performed were designed to provide data for comparing the two scheduling heuristics, the closest customer heuristic and time saved heuristic, and to identify the effects of the decision rule parameters on the solutions developed. A discussion based on the analysis of experimental results listed in TABLE IV.2 to TABLE IV.6 is given below:

4.3.1 Effects of the Scheduling Heuristics and the Dispatching Decision Rule Parameters ME and MB

TABLE IV.7 lists the differences in performance measures resulting from the scheduling heuristics used in all experiments except those which were designed for testing the results of altered work policy or the application of the modified decision rules. The results are as follows:

(a) When the sectoring mechanism designed in this research is inactive, (in all experiments using sectoring mechanism S(1) or S(2),) T.S.H. always generates shorter mean travel time per customer than C.C.H., although the difference is small. T.S.H. also produces a lower mean service time per customer, and usually results in lower values of both service time standard deviation per customer and mean delivery time per customer, as well as delivery time standard deviation per customer. The implication is that solution methods with T.S.H active are more preferable in solving this scheduling problem.

(b) When the sectoring part of the dispatching decision rule is inactive, the mean travel time per customer (also the mean service time per customer) decreases and the mean delivery time per customer increases as the value of MB becomes larger. However, service time standard deviation per customer is relatively unaffected by the value of this parameter, as opposed

TABLE IV.7 SUMMARY OF DIFFERENCES IN PERFORMANCE MEASURES DUE TO THE SCHEDULING HEURISTICS USED IN THE EXPERIMENTS

EXPER.DESIGN			DIFFERENCE IN PERFORMANCE MEASURES (C.C. LESS T.S.)				
ME	MB	S	TRAV.TIME PER CUST.	MEAN SER. TIME PER CUST.	S.D.OF SER. TIME PER CUST.	MEAN DEL. TIME PER CUST.	S.D.OF DEL. TIME PER CUST.
10000	0	S(1)	0.49	0.49	0.28	3.31	3.08
10000	5	S(1)	0.44	0.44	0.47	13.72	7.37
10000	10	S(1)	0.69	0.69	-0.04	9.21	26.15
10000	15	S(1)	0.29	0.29	0.17	2.06	43.25
30	0	S(1)	0.29	0.29	-0.09	6.47	13.63
25	0	S(1)	0.19	0.19	0.48	13.12	36.85
23	0	S(1)	0.62	0.62	1.15	-47.24	-25.99
21	0	S(1)	0.01	0.01	3.97	79.75	22.41
10000	0	S(2)	0.21	0.21	0.04	-3.84	-1.06
10000	0	S(3)	0	0	0	-0.18	-0.09
10000	0	S(4)	-0.30	-0.30	-0.29	2.70	9.28
50	0	S(4)	-0.29	-0.29	-0.29	2.70	9.28
25	5	S(1)	-0.02	-0.02	1.56	7.09	45.43

TIME MEASURED IN MINUTES.

to the delivery time standard deviation per customer which increases as its value increases. These results imply that if the operating cost of the vehicle fleet (to which mean travel time per customer and mean service time per customer are directly related) is important, then a sufficiently large value should be assigned to MB. If it is desirable to compromise the operating cost for higher efficiency in service in order to attract customers, then MB should be set to a smallest value possible.

(c) When the sectoring part of the dispatching decision rules is inactive, the mean travel time per customer (also the mean service time per customer) decreases and the mean delivery time per customer usually increases as the value of ME becomes smaller. A larger value of this parameter usually results in smaller service time standard deviation per customer and smaller delivery time standard deviation per customer. These imply that if the mean travel time per customer or the mean service time per customer is important, then a small enough value should be assigned to ME. If the mean delivery time per customer is more important, then ME should be set to a largest value possible.

4.3.2 Sectoring Effect

The performance measures listed in TABLE_IV.4 and TABLE_IV.5 indicate that all five measures are affected by the sectoring mechanism.

Comparing the results of the experiments using sectoring mechanism S(1) and S(2), the latter mechanism leads to a decrease in mean travel time per customer, mean and standard diviation of service time per customer while it increases the delivery time per customer mean and standard deviation. This suggests that increasing the number of sectors will yield a reduction in travel time and hence mean service time per customer, but an accompanying loss in customer service quality will probably occur.

When sectoring mechanism S(3) is used in conjunction with either one of the two scheduling heuristics, about 19 minutes mean travel time per customer (hence about 29 minutes mean service time per customer) is achieved with only 19 customers being served within the entire six day period. This makes the low value in mean delivery time per customer meaningless. It appears that sectoring mechanism S(3) (ALLTRANS's sectoring) as a part of the decision rule conditions is not appropriate in solving this scheduling problem. In another words, this sectoring mechanism simply does not combine well with the other parts of the decision rules. The results of experiments (3) and (4) in SET D support this conclusion. As seen in TABLE_IV.8, solution based on C.C.H. produces a mean travel time per customer of 15 minutes (hence mean service time per customer is

TABLE IV.8 SUMMARY OF RESULTS OF EXPERIMENTS USING SECTORING MECHANISM S(3)

EXPERIMENTAL			DESIGN	TRAV. TIME PER CUST.	MEAN SER. TIME PER CUST.	S.D.OF SER. TIME PER CUST.	MEAN DEL. TIME PER CUST.	S.D.OF DEL. TIME PER CUST.	TOTAL NO. OF CUST. SERVED
ME	MB	S	DEC. RULES						
10000	0	S(3)	DOLL'S D.R. WITH C.C.	19	29	72	101	59	19
10000	0	S(3)	MODIFIED D. R.WITH C.C.	15	25	5	148	80	178
10000	0	S(3)	DOLL'S D.R. WITH T.S.	19	29	72	102	60	19
10000	0	S(3)	MODIFIED D. R.WITH T.S.	15	25	5	146	75	181

TIME MEASURED IN MINUTES.

25 minutes) with a total of 178 customers being served in six days. With T.S.H., mean travel time per customer is 15 minutes (hence mean service time per customer is 25 minutes) with a total of 181 customers being served in six days. This means that, the decision rules were unable to operate under sectoring mechanism S(3).

More important are the results of the experiments using sectoring mechanism S(4). This sectoring mechanism was designed with due consideration of the problem structure as well as insight into the operation of the decision rules. It is seen in TABLE IV.9 that when C.C.H. is used, sectoring mechanism S(4) can achieve a reduction in mean travel time and hence mean service time per customer as compared to those with an inoperative sectoring mechanism (by using sectoring mechanism S(1)). At the same time, mean delivery time per customer increases very rapidly. However, when T.S.H. is used, mean travel time and hence mean service time per customer showed an increase together with an increase in mean delivery time per customer as compared to the results of the experiments using sectoring mechanism S(1). The unexpected increase in mean travel time and mean service time per customer can be explained by the design of this sectoring mechanism itself. With this sectoring mechanism, the area being served is subdivided into smaller regions according to the clustering of customer demands. In this scheduling problem, customer demands are concentrated in the down-town area, thus increasing the density of customers within small areas in the subregions located in down-town districts. Such subdivision of the area can accomplish a more efficient

TABLE IV.9 COMPARISON ON RESULTS OF EXPERIMENTS USING SECTORING MECHANISM S(1) AND S(4) RESPECTIVELY

EXPERIMENTAL DESIGN				TRAV. TIME PER CUST.	MEAN SER. TIME PER CUST.	S.D.OF SER. TIME PER CUST.	MEAN DEL. TIME PER CUST.	S.D.OF DEL. TIME PER CUST.
ME	MB	S	SCHEDULING HEURISTIC USED					
10000	0	S(1)	C.C.	13	23	6	132	70
10000	0	S(4)	C.C.	13	23	16	421	303
10000	0	S(1)	T.S.	13	23	5	129	67
10000	0	S(4)	T.S.	13	23	17	418	294

TIME MEASURED IN MINUTES.

performance for C.C.H. than for T.S.H..

It is evident that the performance of the decision rules depends largely on the specification of sectoring. The number of sectors and their geographic limits depend on the area size and the expected demand density, while individual sector would be defined by the spatial distribution of customer demands. Theoretically, the definition of each sector should be changed dynamically to allow the most efficient use of each vehicle in solving a specific scheduling problem. In practice, however, sectors cannot be dynamically redefined. A powerful sectoring mechanism is difficult to obtain, but it should be problem oriented.

4.3.3 Effect of Combinations of Decision Rule Conditions

Experiments (5) and (6) in SET D, using C.C.H. and T.S.H. respectively, have been performed with ME=50, MB=0 and sectoring mechanism S(4) active. In choosing values for ME and MB, several preliminary experiments were performed. These experiments had to be terminated because when ME was set to 50 or less, the backlog of customer requests grew to a point where the assigned computer memory space was exceeded. Similar phenomena occurred if MB was set larger than 0. These computational problems are caused by the fact that for the six day period, the 201 customer requests were scattered in 17 sectors. During the simulated period, there was usually only a limited number of customer requests for delivery to most of these 17 sectors. Hence, when relatively low

ME or relatively large MB values were used in conjunction with sectoring mechanism S(4), it was impossible to develop schedules and dispatch vehicles to follow them. Hence, the experiments failed to find out whether a combination of several dispatching decision rule parameters can minimize the trade-off between low mean travel time and low mean delivery time. The results of experiments (5) and (6) in SET D were found to be close to those of the experiments in SET C using sectoring mechanism S(4) with ME and MB inoperative.

As listed in TABLE IV.10, a comparison of the results of experiments (7) and (8) in SET D to those of the four experiments using either scheduling heuristic and sectoring mechanism S(1), with ME=25 and MB=0 or ME=10000 and MB=5 indicates the following:

(a) When C.C.H. is used: with ME=25 and MB=5, there is a 1 minute decrease in travel time per customer (hence also in mean service time per customer) accompanied by a 5 minutes increase in mean delivery time per customer compared to the results of experiment with ME=10000 and MB=5. There is also a 1 minute decrease in travel time per customer (so is mean service time per customer) together with a 4 minutes increase in mean delivery time per customer as compared to the results of the experiment with ME=25 and MB=0. The standard deviation of service time per customer and the standard deviation of delivery time per customer increase as compared to both experiments.

TABLE IV.10 TRADE-OFF BETWEEN LOW MEAN TRAVEL TIME AND LOW MEAN DELIVERY TIME BY MEANS OF COMBINATION OF CONDITIONS OF DISPATCHING DECISION RULES

EXPERIMENTAL DESIGN				TRAV. TIME PER CUST.	MEAN SER. TIME PER CUST.	S.D.OF SER. TIME PER CUST.	MEAN DEL. TIME PER CUST.	S.D.OF DEL. TIME PER CUST.
ME	MB	S	SCHEDULING HEURISTIC USED					
25	5	S(1)	C.C.	11	21	8	159	140
25	0	S(1)	C.C.	12	22	7	155	125
10000	5	S(1)	C.C.	12	22	6	154	93
25	5	S(1)	T.S.	11	21	7	152	94
25	0	S(1)	T.S.	11	21	7	142	88
10000	5	S(1)	T.S.	11	21	5	140	86

TIME MEASURED IN MINUTES.

(b) When T.S.H. is used: with ME=25 and MB=5, there is no change in travel time per customer (also in mean service time per customer) as compared to the results of the other two experiments. For mean delivery time per customer, there is a 12 minutes increase compared to the result of the experiment with ME=10000 and MB=5, and a 10 minutes increase as compared to that of the experiment with ME=25 and MB=0. In most cases, the standard deviation of service time per customer and standard deviation of delivery time per customer increase as compared to both experiments.

These results demonstrate that certain combination of conditions of the dispatching decision rules can minimize the trade-off required between low mean travel times and low mean delivery times to serve customers.

4.4 Other Experiments

APPENDIX II lists the pertinent schedule time information on individual schedules from six different experiments.

In the first pair of experiments with ME=10000,MB=0 and sectoring mechanism S(1) active, 52 per cent of the schedules served contain only one customer when C.C.H. is used. This changes to 46 per cent when T.S.H. is used. These singleton schedules (i.e., schedules containing only one customer) tend to increase the mean travel time per customer. The generation of the singleton schedules results from a broad dispersion of customer demands in this given problem.

The second pair of experiments chosen take on parameter values of ME=50, MB=0 and active sectoring mechanism S(4), using C.C.H. and T.S.H. respectively. About 30 per cent of the schedules were found to be singleton schedules, suggesting that this sectoring mechanism failed to eliminate singleton schedules. With sectoring mechanism S(4) active, the area being served is subdivided into smaller regions which aggregate customer demands. Rejection of singleton schedules in a region increases the backlog of customer demands, because according to Doll's dispatching rules, no vehicle can be dispatched to the next sector unless at least one vehicle has been dispatched in the sector being considered.

In the third pair of experiments which has ME = 25 and MB = 5, with sectoring mechanism S(1) active, using C.C.H. and T.S.H. respectively, it is found that each schedule contains at least 3 customers. Travel time per customer was reduced from 13 to 11 minutes as compared to the results of the first pair of experiments. This shows that given a restriction on the minimum level of efficiency and/or a minimum backlog of customer requests, singleton schedules will be rejected as a result of the long travel time required. Of course, restriction in travel time per customer will be accompanied by increasing time to satisfy a customer after its arrival, when restriction in efficiency level and/or backlog of customer requests is set.

Another two experiments, using C.C.H. and T.S.H. respectively, and with ME=10000, MB=0,and sectoring mechanism S(1) active, were performed to investigate the scheduling results on extending the operation hours from five to ten hours per day. It is found (see TABLE IV.6 , experiments (1) and (2)) that by altering the work policy as discribed, no change occurs in travel time (hence mean service time) per customer but there is an increase in the standard deviation of service time per customer, and the mean and standard deviation of delivery time per customer . The conclusion is that extending operation hours can only enable the completion of service for all customer requests occuring within the same day but the travel time (hence mean service time) per customer will not be affected.

CHAPTER V

CONCLUSIONS

In this study, Doll's decision rules have been successfully applied to an actual scheduling situation. The performance of Doll's decision rules on this specific scheduling situation is summarized below.

(a) For this actual scheduling problem, Doll's decision rule methods do not improve the solutions in terms of reducing travel time per customer. Application of these methods, however, can possibly produce higher service quality in terms of reducing the time to satisfy a customer requirement after its occurrence. It is found that the volume and dispersion of customer requests in this scheduling problem are probably not appropriate for allowing competent performance of the decision rules.

(b) Compared with the closest customer scheduling heuristic, the time saved scheduling heuristic results in consistently shorter mean travel time (hence mean service time) per customer and, in many cases, a shorter time to satisfy a customer request after its occurrence. The time saved heuristic is therefore shows better performance in solving this scheduling problem.

(c) Both maximum efficiency condition and minimum backlog condition of the dispatching decision rules can affect the mean travel time (hence mean service time) per customer and mean time to satisfy a customer request after its occurrence. These times cannot be jointly minimized. However the trade-off between them can be control by using different combinations of parameters of the dispatching decision rules, especially the maximum efficiency parameter and the minimum backlog parameter.

(d) Geographical restriction is found to have effects on all five performance measures, i e travel time per customer, mean and standard deviation of service time per customer, mean and standard deviation of delivery time per customer. The effect of this restriction depends basically on the design of a sectoring mechanism.

For the vehicle-scheduling problem under study, it is almost impossible to examine all important topics in detail. Some topics, however, should be mentioned as potentially fruitful areas for further research. They include:

(a) Studies on the effects of the within sector condition of the dispatching decision rules, with emphasis on the design of a specific sectoring mechanism;

(b) Studies on the use of combinations of conditions of the dispatching decision rules to control the trade-off between mean travel times (or mean service times) per customer and mean times to satisfy a customer request after its occurrence.

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APPENDIX I

Records of Schedules Supplied by ALLTRANS and Customer Information Obtained from These Records

CASH AND DELIVERY RECORD

Equipment No. *PUD 007* Station ____________

Driver's Name *Bill Schultz* *left terminal 8:57 a.m.* Date *7-20-73*

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
CY 754	W. McMahon	350		(1)	arrived	9:00 a.m.	left 9:07 a.m.		
EN 010	GE Shnier	145		(4)	"	10:30 a.m.	" 10:35 a.m.		
TO 815	Woodwards	945		(2)	"	9:15 a.m.	" 9:28 a.m.		
TO 814	"	228		same as (2)					
TO 813	H.B.W. Weston	320		(3)	"	9:22 a.m.	" 9:55 a.m.		Coffee
CY 737	Gennely Floor	1750		(5)	"	10:50 a.m.	" 11:05 a.m.		
CY 926 A	Burlington Carpet	425		(6)	"	11:10 a.m	" 1:20 p.m.		Finished

CASH AND DELIVERY RECORD

Equipment No. PUD 007 | Station

Driver's Name Bill Schultz | Left terminal 12:30 a.m. | Date 7-16-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
WG 453	Anthes	300		(1)	arrived	12:50 p.m.	left	12:54 p.m.	
TO 039	Regent	578		(2)	"	1:00 p.m.	"	1:05 p.m.	
TO 579	Narecco	38		(3)	"	1:10 p.m.	"	1:14 p.m.	
TO 008	Pac. Commu.	300		(4)	"	1:30 p.m.	"	1:35 p.m.	
									Finished

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 007 Station

Driver's Name Bill Schultz Date 7-16-73

Left terminal 8:45 a.m.

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 076	Arbutus Drs.	110		(2)	arrived	9:15 a.m.	left 9:	20 a.m.	
TO 023	Jantzen	140		(1)	"	9:05 a.m.	" 9:	10 a.m.	
CY 594	Murphy Stat.	21		(6)	"	10:05 a.m.	" 10:	08 a.m.	Coffee
WG 439	Fogg Bros.	335		(4)	"	9:45 a.m.	" 9:	48 a.m.	
OA 872	W. P. S.	2069		(3)	"	9:25 a.m.	" 9:	40 a.m.	
CY 579	Av. Bus	206		(5)	"	9:50 a.m.	" 10:	00 a.m.	
EN 664	Smith Barger	1680		(7)	"	10:30 a.m.	" 10:	45 a.m.	
									Finished

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 501   Station ____________

Driver's Name Steve Stone   Left yard 8:40 a.m.   Date 7-16-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
WG 456	Maco Ind.	1200		(1)	Arrived	8:55 a.m.	left	9:05 a.m.	
WG 738	Geo. N. Jackson	3841		(2)	"	9:15 a.m.	"	9:37 a.m.	
TO 022	Malkin	879		(3)	"	9:47 a.m.	"	10:00 a.m.	Coffee
								10:15 a.m.	
									Finished

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Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 007 Station

Driver's Name Bill Schultz Left terminal 9:15 a.m. Date 7-17-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 478	W.D. Gray	5800		(1)	Arrived	9:35 a.m. left	9:55 a.m.		
TO 617	Lancair	250		(2)		10:00 a.m.	10:03 a.m.		
ML 488	Ray. Typewriter	64		(6)		10:55 a.m.	11:05 a.m.		
ML 489	Paleon Type.	128	same as (6)						
TO 566	Malkin	105		(3)		10:20 a.m.	10:26 a.m.		
TO 483	Malkin	140	same as (3)						
TO 159	"	686	" " "						
TO 147	Western Glass	198		(4)		10:30 a.m.	10:35 a.m.		
ML 509	Jantzen	374		(5)		10:40 a.m.	10:45 a.m.		
TO 630	Jantzen	601	same as (5)						
TO 613	Crystal	204		(7)		11:10 a.m.	11:20 a.m.		
TO 134	Henry Elec.	1280		(8)		11:23 a.m.	11:30 a.m.		
									Finished

CASH AND DELIVERY RECORD

Equipment No. PUD007

Station

Driver's Name Bill Schultz

Left Terminal 1:00 p.m.

Date 7-17-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
ML 540	Jantzen	1610		(2)	arrived	1:25 p.m.	left	1:30 p.m.	
ML 485	Imperial Auto	570		(4)		1:50 p.m.		2:05 p.m.	Finished
TO 124	Eatons	290		(1)		1:10 p.m		1:14 p.m	
ML 538	Coke Linotype	590		(3)		1:35 p.m.		1:40 p.m.	

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Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 501 Station

Driver's Name Steve Stone Left yard 8:40 a.m. Date 7-17-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
ML 539	Provincial phy.	122		(1)	arrived	8:50 a.m.	left	8:55 a.m.	
TO 133	Nil Steel Ag.	11		(2)		9:05 a.m.		9:10 a.m.	
TO 127	Vanwood	550		(3)		9:15 a.m.		9:25 a.m.	
TO 477	Nil Steel	165	sent to	2201	cash	collected			
				(4)		9:30 a.m.		9:35 a.m.	
TO 151	NA Scientific	364		(6)		10:10 a.m.		10:20 a.m.	
TO 484	Ackland	268		(5)		9:40 a.m.		9:45 a.m.	
TO 160	Western Marine	480		(7)		10:25 a.m.		10:35 a.m.	
TO 538	Grinnell	583		(8)		10:45 a.m.		10:55 a.m.	
ML 496	W Mimogan	5100	sent to	1072	Hamilton				
				(9)		11:00 a.m.		11:45 a.m.	

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 008

Station

Driver's Name John Nobb

Date 7-17-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
WG 709	Highland	60		Cash collected	(1)	arrived	9:30 a.m.	left	9:39 a.m.
TO 533	Elec. Supply	156			(2)		9:48 a.m.		9:50 a.m.
ML 549	Woodwards	175			(4)		10:16 a.m.		10:21 a.m.
TO 113	Nedco	1194			(3)		10:00 a.m.		10:14 a.m.
EN 715	Acme	2875			(5)		10:28 a.m.		10:45 a.m.

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. *PUD 008* Station ______

Driver's Name *John Nobb* Date *7-17-73*

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 104	G.E. Sher	382		(1)	arrived	1:35 p.m.	left 1:37 p.m.		
TO 590	E.B. Peerless	36		(2)		2:00 p.m.	2:02 p.m.		
TO 588	City College	670		(3)		2:09 p.m.	2:13 p.m.		
TO 574	Fletchers	216		(4)		2:20 p.m.	2:22 p.m.		
EN 713	7-cities	86		(5)		2:30 p.m.	2:58 p.m.		

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 007 Station

Driver's Name Bill Schultz left terminal at 3:00 p.m. Date 7-18-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
ML 037	C. Liq. Air	67		(3)	arrived at	3:50 p.m.	left	3:52 p.m.	
ML 358	G. N. Johnson	11		(4)		3:55 p.m.		3:59 p.m.	Finished
TO 113 A	Nedco	W/C		(2)		3:47 p.m.		3:48 p.m.	
ML 013	Edn. Printing	2430		(1)		3:20 p.m.		3:45 p.m.	
ML 357	″	2430		same as (1)					

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 007

Station

Driver's Name Bill Schultz

Left terminal at 8:40 a.m.

Date 7-18-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 889	Cdn. Red Cross	3250		(1)	arrived	9:00 a.m.	left 9:30	a.m.	
CY 757	Burns	495	rush	(3)		10:01 a.m.	10:30	a.m.	
OA 937	Woodwards	662		(2)		9:40 a.m.	10:00	a.m.	
TD 228	Jackson Agency	186		(4)		11:00 a.m.	11:05	a.m.	
LN 101	Chrysler	1254		(5)		11:06 a.m.	11:11	a.m.	
EN 846	Metro Vending	2000		(6)		11:20 a.m.	11:40	a.m.	
									Finished

CASH AND DELIVERY RECORD

Equipment No. PUD 501

Station

Driver's Name Steve Stone

Left yard 8:50 a.m.

Date 7-18

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
ML 328	Leisure time	225		(1)	9:05 a.m. arrived	9:15 a.m. left			
ML 038	Aero Garment	35		(2)	9:17 a.m.	9:18 a.m.			
TO 646	McGregor	315		(3)	9:23 a.m.	9:28 a.m.			
	Thompson								
WG 691	King Elec.	355		(4)	9:35 a.m.	9:40 a.m.			
TO 227	NA Scientific	499		(5)	9:45 a.m.	9:50 a.m.			
ML 951	Wolff Marine	273		(6)	9:55 a.m.	10:00 a.m.			Coffee
EN 845	Amco Service	2150		(7)	10:25 a.m.	11:15 a.m.			
CY 776	F. Dexel	864		(8)	11:30 a.m.	11:45 a.m.			

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 501

Station

Driver's Name Steve Stone

Left yard 8:45 a.m.

Date 7-19-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 626	Van. Gen. Hosp.	1178		(2)	arrived	9:15 a.m.	left 9:25 a.m.		
CY 752 A	Fred Surridge	WCA		(6)		10:30 a.m.	10:37 a.m.		
EN 899	Jon Edens	180		(1)		9:05 a.m.	9:10 a.m.		
TO 643	Shoppers Drug	101		(9)		11:10 a.m.	11:20 a.m.		
TO 644		80	same as (9)						
EN 913	Levitt Safety	2065		(3)		9:30 a.m.	9:50 a.m.		
TO 633	Shell Eda	145		(10)		11:30 a.m.	11:35 a.m.		
ML 450	Clarke Sim.	33		(8)		10:55 a.m.	11:00 a.m.		
TO 783	Verita Bao	33		(4)		9:55 a.m.	10:00 a.m.		Coffee
WG 799	Fred Oshere	618		(5)		10:20 a.m.	10:25 a.m.		
WG. 798	Pant Padler	34		(11)		11:45 a.m.	11:50 a.m.		
ML 384	Anglo Photo	800		(7)		10:42 a.m.	10:50 a.m.		

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Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 008 Station

Driver's Name John Nobb Date 7-19-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
ML 333	Cdn. SKF	440		(1)	Arrived	1:52 p.m. left	1:54 p.m.		
WG 813	"	78	same as (1)						
ML 361	Hugh Divens	712		(2)		1:55 p.m.	1:58 p.m.		
CY 844	UR. Mag	50		(3)		1:59 p.m.	2:00 p.m.		
WG 802	Brook Bond	150		(4)		2:02 p.m.	2:05 p.m.		
LN 093	L. Bessett	150		(5)		2:09 p.m.	2:10 p.m.		
LN 094	Hoffan	56		(6)		2:15 p.m.	2:16 p.m.		
TO 982	S. S.	1427		(7)		2:30 p.m.	2:47 p.m.		
TO 813[A]	HBC	W/C		(8)		3:05 p.m.	3:30 p.m.		
TO 989		193	same as (8)						
TO 988		331	same as (8)						
									83

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 008 | Station ______

Driver's Name John Nibb | Date 7-19-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 001	National Spice	300		(1)	arrived	9:18 a.m.	left	9:20 a.m.	
ML 447	Shoppers Drug	140		(2)	"	9:23 a.m.	"	9:35 a.m.	
ML 499	Westinghouse	540		(3)		9:39 a.m.		9:45 a.m.	
ML 514A	Signode Fires.	WCA		(4)		9:47 a.m.		10:00 a.m.	
TO 978	Pastle Owens	1285		(5)		10:00 a.m.		10:05 a.m.	

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 008

Station

Driver's Name John Nibb

Date 7-19-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
ML 024	Jantzen	745		(1)	arrived	11:30 a.m.	left 11:50 a.m.		
ML 479	"	2354	same	as (1)					
ML 452	"	1153	same	as (1)					
TO 650	"	1132	same	as (1)					

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 007

Station

Driver's Name Bill Schultz Left terminal 12:30 p.m.

Date 7-19-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
ML 476	J. Wolton	620		(1)	arrived	1:00 p.m. left	1:05 p.m.		
TO 987	J. P. Delf	280		(3)		1:30 p.m.	1:35 p.m.		
ML 474	Ind. Screw	7151		(2)		1:05 p.m.	1:17 p.m.		
ML 985	Longs	300		(4)		1:50 p.m.	1:55 p.m.		
TO 654	D. Thompson	740		(6)		2:20 p.m.	2:30 p.m.		Finished
TO 980	Zellers	574		(5)		2:00 p.m.	2:15 p.m.		

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 007 Station

Driver's Name Bill Schultz Left Terminal at 9:20 a.m. Date 7-19-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
EN 911	Vanc. Appliances	700		(1)	arrival	9:00 a.m.	left 9:13 a.m.		
ML 975	Pace Ind.	38		(4)		9:30 a.m.	9:34 a.m.		
TO 962[A]	Wholesale Appliances	WCA		(3)		9:25 a.m.	9:27 a.m.		
TO 974	Cda. printing	84		(2)		9:15 a.m.	9:20 a.m.		
ML 492	Ernest Green	2992		(6)		9:40 a.m.	9:52 a.m.		Coffee
TO 903	West port	3075		(5)		9:25 a.m.	9:30 a.m.		
ML 504	Monty Hills	200		(7)		10:15 a.m.	10:35 a.m.		Finished

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Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 501 | Station ______

Driver's Name Steve Stone | Left yard 12:45 p.m. | Date 4-2-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 062	Pitney Bowes	165		(1)	arrived	12:58 p.m.	left 1:03 p.m.		
TO 065	"	DCS	same as (1)						
EN 114	Kelly Spring Field	650		(2)		1:15 p.m.	1:30 p.m.		
ML 989	Cda Packers	335		(3)		1:33 p.m.	1:37 p.m.		
EN 654	Jan Edens	220		(9)		3:10 p.m.	3:12 p.m.		
TO 121	Rayomer	35		(8)		2:55 p.m.	3:08 p.m.		
WG 159	McGroer Thompson	1320		(5)		2:05 p.m.	2:13 p.m.		
EN 759	Sharinger flower	350		(4)		1:45 p.m.	1:55 p.m.		
TO 059	Thorcraft Ind.	150		(6)		2:25 p.m.	2:38 p.m.		
ML 414	Scott Agency	37		(7)		2:43 p.m.	2:46 p.m.		Coffee
WG 188	Acklands	665		(10)		3:40 p.m.	3:50 p.m.		
									8

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 501

Station

Driver's Name Steve Stone

left yard 9:45 a.m.

Date 4-2-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
EN 762	Martan Eng.	149		(1)	arrived	10:05 a.m.	left 10:09 a.m.		
WG 151	B.C. Engines	360		(2)		10:13 a.m.	10:15 a.m.		
WG 147	Carter Temro	87		(3)		10:22 a.m.	10:25 a.m.		
WG 161	Deakin Equip.	1017		(4)		10:28 a.m.	10:40 a.m.		
TO 723	Mucedos	4075		(5)		10:43 a.m.	10:50 a.m.		Coffee

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 007 Station

Driver's Name Bill Schultz left terminal 9:20 a.m. Date 4-2-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
ML 843	Jantzen	855		(1)	arrived	9:40 a.m.	left 9:45 a.m.		
CY 584	Ham. Harvey	1405		(2)		9:50 a.m.	10:00 a.m.		
ML 840	Silver Line	50		(3)		10:25 a.m.	10:30 a.m.		
LN 829	Motor Vessel	163		(4)		10:40 a.m.	10:50 a.m.		
CY 641	Bonar's Bemis	6415		(5)		10:55 a.m.	12:55 p.m.		

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 257 | Station

Driver's Name T. Spinere | Date 4-2-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
CY669A	Concord Ind.	UCA		(1)	In	8:45 a.m. out	8:50 a.m.		
TO126	F. Drexel	530		(2)		8:50 a.m.	8:55 a.m.		
CY561	Western Packing	400		(3)		9:00 a.m.	9:10 a.m.		
WG 980	Western Packing Warehouse	1195		(4)		9:10 a.m.	9:30 a.m.		
ML 923	Progressive Manuf.	122		(5)		9:35 a.m.	9:40 a.m.		
TO 990	Ind. Metal	2050		(6)		9:45 a.m.	10:15 a.m.		Coffee
TO 927	Wickman Tyl	4884		(7)		10:30 a.m.	11:15 a.m.		
ML 104	Apex Brush	142		(8)		11:20 a.m.	11:25 a.m.		
TO 782	Wickman Tyl	366	same as (7)						
TO 769	Gundy Bilmac	833		(9)		11:30 a.m.	11:35 a.m.		

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 239 Station

Driver's Name N.T. Vannier Date 4-2-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
WG 971	Harding Carpets	150		(1)	In	8:45 a.m. Out	8:50 a.m.		
ML 018	Southwestern	738		(2)		9:05 a.m.	9:10 a.m.		
	Drug								
WG 574	PHE Perm.	2080		(3)		9:20 a.m.	10:10 a.m.		
EN 723	Taylor Ind.	375		(4)		10:30 a.m.	10:35 a.m.		
CY 647	Pump Power	100		(5)		10:40 a.m.	10:45 a.m.		
ML 798	Aero Garment	85		(6)		10:50 a.m.	11:00 a.m.		
ML 836	"	292	same as (6)						
CY 572	A-1 Steel	42		(9)		11:20 a.m.	11:25 a.m.		
ML 980	Van Fancy	540		(7)		11:00 a.m.	11:10 a.m.		
	Sausage								
EN 725	Airco Prods.	84		(8)		11:10 a.m.	11:15 a.m.		
ML 981	Vitco Sales	2094		(10)		11:30 a.m.	11:50 a.m.		

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 501 Station

Driver's Name Steve Stone Date 4-3-73

Left yard 9:15 a.m.

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
ML 381	Broadway Cloth	1200		(1)	arrived	9:32 a.m.	left 9:55 a.m.		
TO 962	Levett	832		(2)		10:05 a.m.	10:15 a.m.		
TO 626	Intl Harvester	117		(4)		10:32 a.m.	10:37 a.m.		Coffee
ML 618	Eda. Plastics	235		(3)		10:22 a.m.	10:26 a.m.		
ML 394	3 Vets	300		(5)		11:00 a.m.	11:03 a.m.		
WG 453	AIM	600		(7)		11:15 a.m.	11:29 a.m.		
ML 380	Nelson Land	224		(8)		11:30 a.m.	11:35 a.m.		
TO 385	Scott Agn.	898		(9)		11:40 a.m.	11:50 a.m.		
TO 941	Malkin	3156		(10)		11:53 a.m.	12:10 p.m.		
TO 089	AM Dowelargl	250		(14)		1:20 p.m.	1:25 p.m.		
TO 090	Butt & Bowes	80		(11)		12:45 p.m.	12:49 p.m.		
WG 496	Geo Sparling	430		(6)		11:06 a.m.	11:12 a.m.		
TO 331	Up John	370		(12)		12:58 p.m.	1:08 p.m.		
TO 058	John Russell	434		(13)		1:12 p.m.	1:18 p.m.		

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 239

Station

Driver's Name N.T. Vannier

Date 4-3-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 155	Granduc	200		(1)	arrived	8:50 a.m.	left	9:00 a.m.	
TO 610	Sterling	65							
	Hardware			(3)		9:15 a.m.		9:20 a.m.	
TO 087	Cruckley Elec.	125		(4)		9:25 a.m.		9:30 a.m.	
BOL	Can. Soya	495		(2)		9:05 a.m.		9:10 a.m.	
TO 697	Vanward	1330		(5)		9:35 a.m.		*11:00 a.m.	
							(back 3 times)		
ML 214	W. Maurene	240		(15)		1:00 p.m.		1:10 p.m.	
EN 651	Hope Furn.	30		(7)		10:20 a.m.		10:25 a.m.	
TO 171	E.S.B. Can.	220		(16)		1:12 p.m.		1:15 p.m.	
TO 158	A.B.C. Elec.	108		(17)		1:17 p.m.		1:21 p.m.	
TO 137	Ammo Power	289		(11)		11:30 a.m.		11:36 a.m.	
WG 504	Fluthams	10		(13)		11:50 a.m.		12:10 p.m.	
	Wholesale								
ML 405	Drape Shire	56		(9)		11:15 a.m.		11:22 a.m.	
EN 731	"	144	same as (9)						
TO 619	J. Phillips	90		(18)		1:21 p.m.		1:23 p.m.	
ML 209	Aero Garm.	473		(8)		11:05 a.m.		11:08 a.m.	
LN 816	D.B. Lewis	334		(7)		10:10 a.m.		10:15 a.m.	
EN 755	Drape Shire	276	same as (9)						

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. ______________________ Station ______________________

Driver's Name ______________________ Cont. Date ______________________

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 622	Kirkland	360		(6)	arrived	9:50 a.m.	left 10:00 a.m.		
WG 460	Western Wholesale	107		(10)		11:25 a.m.	11:27 a.m.		
TO 067	Campell & Gr.	124		(12)		11:40 a.m.	11:42 a.m.		
ML 415	W. Marine	524		(15)		1:00 p.m.	1:10 p.m.		
TO 153	Superior	440		(19)		1:40 p.m.	1:45 p.m.		
WG 502	S.K. Sanitary	517		(14)		12:35 p.m.	12:50 p.m.		

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 007

Station

Driver's Name Bill Schultz

Left terminal 9:05 a.m.

Date 11-3-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
ML 442	Gough Co.	300		(4)	arrived	9:45 a.m.	left 9:47 a.m.		
TO 696	Safty Supply	147		(1)		9:20 a.m.	9:25 a.m.		
ML 260	Seattle Pipe	3510		(7)		10:35 a.m.	11:05 a.m.		
ML 625	Ind. Travell	347		(9)		11:25 a.m.	11:26 a.m.		
LN 998	Langley Elec.	175		(2)		9:30 a.m.	9:35 a.m.		
ML 621	Jantzen	566		(6)		10:15 a.m.	10:30 a.m.		
ML 377	Smith Ball.	725		(8)		11:10 a.m.	11:20 a.m.		
TO 625	Cand. Chain	1800		(10)		11:30 a.m.	11:55 a.m.		Lunch
OA 481	Med. Service	399		(14)		1:15 p.m.	1:25 p.m.		
ML 983	Parthenon	170		(11)		12:40 p.m.	12:55 p.m.		
ML 443	Wesmer & Ross	125		(13)		1:10 p.m.	1:12 p.m.		
ML 373	Nelson Laud	405		(3)		9:35 a.m.	9:40 a.m.		
ML 615	Scott Agn.	86		(5)		9:50 a.m.	9:52 a.m.		Coffee
ML 613	Wesco Ind.	725		(12)		1:00 p.m.	1:05 p.m.		
ML 802 H	ITT Wire	NOA		(15)		1:30 p.m.	1:35 p.m.		
EN 757	Caproco	4		(16)		1:40 p.m.	1:45 p.m.		

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Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 257 — Station

Driver's Name T. Spinere — Date 4-3-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 404	Seaboard Advent.	135		(1)	In	11:20 a.m. Out	11:25 a.m.		
TO 407	Firing Tractor	60		(2)		11:30 a.m.	11:35 a.m.		
TO 391	Cda. Car Pacific	84		(3)		11:40 a.m.	11:45 a.m.		
TO 337	Pacif. Plastic	1972		(4)		11:45 a.m.	12:40 p.m.		Lunch
OA 478	Western Parcel	2579		(5)		12:45 p.m.	1:30 p.m.		

Form No. 205-A

CASH AND DELIVERY RECORD

Equipment No. PUD 257 Station

Driver's Name T. Spinere Date 4-3-73

Pro. No.	Consignee	Weight	Total to Collect	Remarks	Pro No.	Consignee	Weight	Total to Collect	Remarks
TO 338	Star Lanko	60		(1)	On 8:20 a.m.	out	8:30 a.m.		
ML 231	"	166	same as (1)						
OA 480	West Coast Welding	362		(2)	8:35 a.m.		8:40 a.m.		
ML 626	Aero Garm.	470		(3)	8:45 a.m.		8:50 a.m.		
TO 170	Wajax Ind.	385		(4)	8:55 a.m.		9:00 a.m.		
ML 437	B.C. Fancy Sausage	60		(5)	9:05 a.m.		9:10 a.m.		
ML 439	Bitco Sales	710		(6)	9:10 a.m.		9:15 a.m.		
LN 819	Sparton Agn.	4945		(7)	9:20 a.m.		9:40 a.m.		
TO 616	Sinclaire Valentine	2940		(8)	9:45 a.m.		10:00 a.m.		

Form No. 205-A

CUSTOMERS INFORMATION

CUST. NO.	DAY	LOCATION X	Y	DEMAND
1	1	-1180.00	370.00	59.00
2	1	-1020.00	322.00	48.00
3	1	-369.00	-380.00	20.00
4	1	-1292.00	416.00	132.00
5	1	-119.00	-822.00	244.00
6	1	-1321.00	400.00	44.00
7	1	-860.00	435.00	136.00
8	1	-1182.00	50.00	16.00
9	1	-142.00	401.00	261.00
10	1	-1215.00	172.00	13.00
11	1	-1265.00	140.00	3.00
12	1	-1215.00	145.00	196.00
13	1	-1435.00	125.00	81.00
14	1	-1392.00	70.00	355.00
15	1	-356.00	247.00	17.00
16	1	-1427.00	397.00	259.00
17	1	-945.00	160.00	111.00
18	1	-1240.00	160.00	39.00
19	1	-1240.00	100.00	24.00
20	1	-1515.00	-260.00	34.00
21	2	-1210.00	115.00	11.00
22	2	-1392.00	70.00	12.00
23	2	-1316.00	170.00	339.00
24	2	-1890.00	-468.00	14.00
25	2	-1090.00	-849.00	147.00
26	2	-874.00	317.00	1.00
27	2	-1182.00	50.00	289.00
28	2	-1148.00	434.00	35.00
29	2	-1269.00	82.00	14.00
30	2	-1211.00	-300.00	19.00
31	2	-1092.00	-848.00	85.00
32	2	-32.00	230.00	52.00
33	2	-978.00	340.00	40.00
34	2	-1019.00	264.00	42.00
35	2	-1400.00	-880.00	102.00
36	2	-852.00	317.00	19.00
37	2	-1449.00	308.00	373.00
38	2	-1098.00	425.00	26.00
39	2	-874.00	317.00	12.00
40	2	-1260.00	81.00	106.00
41	2	-1410.00	-450.00	7.00
42	2	-1182.00	50.00	22.00
43	2	-1400.00	-480.00	21.00
44	2	-1240.00	128.00	63.00
45	2	-1120.00	80.00	354.00
46	2	-1284.00	-562.00	264.00
47	2	-1460.00	70.00	11.00
48	2	-370.00	-392.00	150.00
49	2	-1350.00	130.00	75.00

50	2	-1075.00	230.00	100.00
51	2	-1092.00	-858.00	7.00
52	2	-910.00	390.00	4.00
53	2	-1400.00	-480.00	62.00
54	2	-1098.00	425.00	58.00
55	3	-974.00	-850.00	505.00
56	3	-910.00	318.00	250.00
57	3	-1445.00	310.00	26.00
58	3	-1364.00	-700.00	1.00
59	3	-1242.00	-795.00	118.00
60	3	-1030.00	412.00	31.00
61	3	-1092.00	-849.00	37.00
62	3	-885.00	402.00	41.00
63	3	-1094.00	-300.00	305.00
64	3	-1258.00	-860.00	17.00
65	3	-945.00	343.00	36.00
66	3	-1386.00	-480.00	46.00
67	3	-1632.00	-860.00	15.00
68	3	-1116.00	67.00	15.00
69	3	-1210.00	115.00	102.00
70	3	-1298.00	-850.00	230.00
71	3	-963.00	-768.00	53.00
72	3	-1540.00	-950.00	236.00
73	4	-1640.00	65.00	18.00
74	4	-1118.00	220.00	244.00
75	4	-1454.00	70.00	3.00
76	4	-20.00	-90.00	48.00
77	4	-1380.00	80.00	215.00
78	4	-1182.00	50.00	540.00
79	4	-1410.00	472.00	2.00
80	4	-1455.00	25.00	122.00
81	4	-120.00	110.00	6.00
82	4	-28.00	229.00	32.00
83	4	-1532.00	87.00	64.00
84	4	-22.00	-65.00	85.00
85	4	-1118.00	220.00	118.00
86	4	-853.00	420.00	42.00
87	4	-1210.00	-885.00	35.00
88	4	-505.00	-652.00	190.00
89	4	-30.00	-59.00	18.00
90	4	-1956.00	72.00	19.00
91	4	-2394.00	57.00	3.00
92	4	-972.00	-850.00	6.00
93	4	-48.00	-509.00	172.00
94	4	-1458.00	436.00	15.00
95	4	-1676.00	148.00	83.00
96	4	-30.00	-60.00	6.00
97	4	-1178.00	130.00	57.00
98	4	-1210.00	-897.00	407.00
99	4	-1810.00	-760.00	3.00
100	4	-623.00	66.00	26.00
104	4	-1620.00	290.00	3.00
102	4	-2169.00	-110.00	1.00
103	4	-1417.00	-886.00	17.00
104	4	-958.00	315.00	103.00
105	5	-958.00	165.00	14.00
106	5	-985.00	115.00	54.00
107	5	-1072.00	278.00	20.00
108	5	-958.00	165.00	14.00
109	5	-80.00	-500.00	12.00

110	5	-979.00	314.00	45.00
111	5	-1024.00	414.00	43.00
112	5	-1020.00	300.00	413.00
113	5	-872.00	391.00	34.00
114	5	-955.00	312.00	62.00
115	5	-610.00	311.00	170.00
116	5	-913.00	180.00	176.00
117	5	-979.00	340.00	205.00
118	5	-1355.00	339.00	5.00
119	5	-352.00	198.00	25.00
120	5	-940.00	225.00	273.00
121	5	-1200.00	100.00	23.00
122	5	-958.00	262.00	7.00
123	5	-1083.00	383.00	6.00
124	5	-1211.00	-100.00	31.00
125	5	-1420.00	120.00	52.00
126	5	-1290.00	86.00	5.00
127	5	-991.00	388.00	106.00
128	5	-958.00	191.00	6.00
129	5	-1360.00	142.00	34.00
130	5	-1098.00	356.00	7.00
131	5	-1095.00	432.00	8.00
132	5	-1214.00	145.00	67.00
133	5	-1068.00	221.00	5.00
134	5	-932.00	282.00	8.00
135	5	-932.00	425.00	394.00
136	5	-422.00	550.00	62.00
137	5	-1110.00	432.00	3.00
138	5	-1081.00	230.00	39.00
139	5	-1092.00	432.00	98.00
140	5	-1066.00	220.00	27.00
141	5	-1270.00	130.00	10.00
142	5	-910.00	390.00	29.00
143	5	-980.00	340.00	160.00
144	6	-1214.00	70.00	74.00
145	6	-805.00	-235.00	26.00
146	6	-1472.00	302.00	19.00
147	6	-1190.00	192.00	9.00
148	6	-910.00	390.00	25.00
149	6	-1686.00	146.00	9.00
150	6	-957.00	230.00	20.00
151	6	-1410.00	355.00	1.00
152	6	-878.00	375.00	29.00
153	6	-1190.00	52.00	8.00
154	6	-950.00	220.00	3.00
155	6	-1213.00	190.00	293.00
156	6	-1805.00	25.00	5.00
157	6	-1290.00	140.00	37.00
158	6	-957.00	227.00	38.00
159	6	-1010.00	300.00	12.00
160	6	-1395.00	460.00	17.00
161	6	-1090.00	168.00	224.00
162	6	-720.00	392.00	5.00
163	6	-1030.00	412.00	269.00
164	6	-990.00	340.00	10.00
165	6	-1100.00	60.00	10.00
166	6	-977.00	405.00	19.00
167	6	-958.00	165.00	15.00
168	6	-1380.00	80.00	51.00
169	6	-958.00	410.00	10.00

170	6	-915.00	318.00	25.00
171	6	-1700.00	100.00	7.00
172	6	-1182.00	50.00	32.00
173	6	-1075.00	413.00	1.00
174	6	-1144.00	136.00	6.00
175	6	-1298.00	82.00	4.00
176	6	-1788.00	70.00	22.00
177	6	-1215.00	190.00	201.00
178	6	-840.00	420.00	44.00
179	6	-1680.00	163.00	41.00
180	6	-1261.00	141.00	23.00
181	6	-1474.00	300.00	41.00
182	6	-1462.00	70.00	26.00
183	6	-1610.00	150.00	22.00
184	6	-1635.00	20.00	103.00
185	6	-1110.00	430.00	19.00
186	6	-1350.00	110.00	18.00
187	6	-1180.00	130.00	195.00
188	6	-760.00	530.00	9.00
189	6	-1300.00	175.00	17.00
190	6	-980.00	340.00	115.00
191	6	-724.00	270.00	45.00
192	6	-980.00	345.00	2.00
193	6	-1220.00	355.00	14.00
194	6	-1190.00	432.00	7.00
195	6	-772.00	452.00	43.00
196	6	-958.00	325.00	41.00
197	6	-1350.00	140.00	4.00
198	6	-1300.00	131.00	13.00
199	6	-1318.00	372.00	31.00
200	6	-910.00	390.00	41.00
201	6	-1300.00	412.00	9.00

APPENDIX II

Schedule Time Information of Six Experiments

TRAVEL TIME INFORMATION ON INDIVIDUAL SCHEDULES IN THE EXPERIMENT WITH ME=10000, MB=0 AND SECTORING MECHANISM S(1), USING CLOSEST CUSTOMER HEURISTIC

DAY	SCHEDULE NO.	TOTAL SCHEDULE TIME	NO.OF CUST. SERVED IN THE SCHED.	SCHED. TIME / CUST.
1	1	137.94	6	22.99
1	2	41.78	1	41.78
1	3	43.77	1	43.77
1	4	154.79	8	19.35
1	5	88.20	3	29.40
1	6	47.08	1	47.08
2	7	44.67	1	44.67
2	8	47.08	1	47.08
2	9	46.08	1	46.08
2	10	251.67	13	19.36
2	11	224.71	12	18.73
2	12	62.01	2	31.01
2	13	71.44	2	35.72
2	14	49.54	1	49.54
2	15	49.57	1	49.57
3	16	48.50	1	48.50
3	17	41.36	1	41.36
3	18	49.53	1	49.53
3	19	168.35	8	21.04
3	20	134.27	6	22.38
3	21	55.93	1	55.93
4	22	50.23	1	50.23
4	23	44.00	1	44.00
4	24	47.93	1	47.93
4	25	239.75	13	18.44
4	26	232.48	11	21.13
4	27	43.77	1	43.77
4	28	78.55	3	26.18
4	29	51.93	1	51.93
5	30	40.80	1	40.80
5	31	40.89	1	40.89
5	32	43.74	1	43.74
5	33	233.64	14	16.69
5	34	134.86	6	22.48
5	35	139.63	7	19.95
5	36	121.69	6	20.28
5	37	81.87	3	27.29
6	38	44.42	1	44.42
6	39	38.61	1	38.61
6	40	49.82	1	49.82
6	41	202.25	12	16.85
6	42	249.74	15	16.65
6	43	248.28	14	17.73
6	44	58.13	2	29.06

TRAVEL TIME INFORMATION ON INDIVIDUAL SCHEDULES IN THE EXPERIMENT WITH ME=10000, MB=0 AND SECTORING MECHANISM S(1), USING TIME SAVED HEURISTIC

DAY	SCHEDULE NO.	TOTAL SCHEDULE TIME	NO.OF CUST. SERVED IN THE SCHED.	SCHED. TIME/CUST.
1	1	136.18	6	22.69
1	2	41.78	1	41.78
1	3	43.77	1	43.77
1	4	140.83	7	20.12
1	5	82.22	3	27.41
1	6	59.21	2	29.60
2	7	44.67	1	44.67
2	8	47.08	1	47.08
2	9	46.68	1	46.68
2	10	165.61	8	20.70
2	11	138.17	6	23.03
2	12	230.98	12	17.77
2	13	71.44	2	35.72
2	14	62.91	2	31.45
3	15	48.50	1	48.50
3	16	41.36	1	41.36
3	17	49.53	1	49.53
3	18	132.99	6	22.16
3	19	118.67	5	23.73
3	20	93.34	4	23.34
4	21	50.24	1	50.24
4	22	44.00	1	44.00
4	23	47.93	1	47.93
4	24	247.66	12	20.63
4	25	121.52	5	24.30
4	26	173.28	9	19.25
4	27	44.78	2	22.39
4	28	43.77	1	43.77
5	29	40.80	1	40.80
5	30	40.89	1	40.89
5	31	43.74	1	43.74
5	32	253.17	15	16.88
5	33	100.58	5	20.12
5	34	200.13	11	18.19
5	35	74.84	3	24.95
5	36	35.73	1	35.73
5	37	42.87	1	42.87
6	38	44.42	1	44.42
6	39	38.61	1	38.61
6	40	49.82	1	49.82
6	41	259.86	15	17.32
6	42	222.47	13	17.11
6	43	219.42	13	16.88

TRAVEL TIME INFORMATION ON INDIVIDUAL SCHEDULES IN THE EXPERIMENT WITH ME =50, MB=0 AND SECTORING MECHANISM S(4), USING CLOSEST CUSTOMER HEURISTIC

DAY	SCHEDULE NO.	TOTAL SCHEDULE TIME	NO.OF CUST. SERVED IN THE SCHED.	SCHED. TIME / CUST.
1	1	41.78	1	41.78
1	2	29.25	1	29.25
1	3	32.27	1	32.27
1	4	37.89	1	37.89
3	5	48.50	1	48.50
3	6	77.89	3	25.96
3	7	40.53	1	40.53
3	8	160.18	9	17.79
3	9	90.96	4	22.74
3	10	87.52	4	21.88
3	11	158.96	9	17.66
3	12	106.04	5	21.21
3	13	63.47	2	31.73
4	14	90.91	4	22.73
4	15	159.78	8	19.97
4	16	155.29	7	22.18
4	17	90.62	3	30.21
4	18	41.49	1	41.49
4	19	94.45	5	18.88
4	20	105.98	6	17.66
4	21	63.38	2	31.69
5	22	48.48	1	48.48
5	23	88.09	3	29.36
5	24	55.53	2	27.77
5	25	128.19	7	18.31
5	26	131.28	7	18.75
5	27	73.05	3	24.35
5	28	132.61	7	18.94
5	29	106.73	5	21.35
5	30	97.94	4	24.48
6	31	107.23	5	21.45
6	32	44.58	1	44.58
6	33	126.59	5	25.32
6	34	49.82	1	49.82
6	35	88.76	4	22.19
6	36	82.76	4	20.69
6	37	30.83	1	30.83

TRAVEL TIME INFORMATION ON INDIVIDUAL SCHEDULES IN THE EXPERIMENT WITH ME =50, MB=0 AND SECTORING MECHANISM S(4), USING TIME SAVED HEURISTIC

DAY	SCHEDULE NO.	TOTAL SCHEDULE TIME	NO.OF CUST. SERVED IN THE SCHED.	SCHED. TIME / CUST.
1	1	41.78	1	41.78
1	2	29.25	1	29.25
1	3	32.27	1	32.27
1	4	37.89	1	37.89
3	5	48.50	1	48.50
3	6	77.89	3	25.96
3	7	40.53	1	40.53
3	8	159.66	9	17.74
3	9	90.29	4	22.57
3	10	87.29	4	21.82
3	11	118.16	6	19.69
3	12	106.04	5	21.21
3	13	63.47	2	31.73
4	14	90.91	4	22.73
4	15	157.86	8	19.73
4	16	155.28	7	22.18
4	17	90.62	3	30.20
4	18	41.49	1	41.49
4	19	93.94	5	18.79
4	20	105.98	6	17.66
4	21	63.38	2	31.69
5	22	48.47	1	48.47
5	23	88.09	3	29.36
5	24	55.53	2	27.76
5	25	128.12	7	18.30
5	26	130.71	7	18.67
5	27	73.04	3	24.35
5	28	132.03	7	18.86
5	29	106.73	5	21.34
5	30	97.31	4	24.33
6	31	106.96	5	21.39
6	32	44.58	1	44.58
6	33	126.40	5	25.28
6	34	49.82	1	49.82
6	35	74.38	3	24.79
6	36	67.53	3	22.51
6	37	30.83	1	30.83

TRAVEL TIME INFORMATION ON INDIVIDUAL SCHEDULES IN THE EXPERIMENT WITH ME =25, MB=5 AND SECTORING MECHANISM S(1), USING CLOSEST CUSTOMER HEURISTIC

DAY	SCHEDULE NO.	TOTAL SCHEDULE TIME	NO.OF CUST. SERVED IN THE SCHED.	SCHED. TIME/CUST.
1	1	137.94	6	22.99
1	2	109.48	5	21.89
1	3	94.59	4	23.65
1	4	97.32	4	24.33
2	5	144.57	6	24.09
2	6	124.98	5	24.99
2	7	146.71	6	24.45
2	8	164.01	8	20.50
2	9	152.29	8	19.04
3	10	123.61	5	24.72
3	11	121.13	5	24.23
4	12	161.67	7	23.09
4	13	116.13	5	23.23
4	14	123.47	5	24.69
4	15	179.78	9	19.97
4	16	164.73	8	20.59
5	17	140.94	6	23.48
5	18	88.44	4	22.11
5	19	162.36	8	20.29
5	20	181.08	10	18.11
5	21	151.88	8	18.98
5	22	124.08	6	20.67
6	23	144.18	6	24.03
6	24	144.10	6	24.01
6	25	116.35	5	23.26
6	26	174.26	10	17.43
6	27	142.89	8	17.86
6	28	141.86	7	20.26

TRAVEL TIME INFORMATION ON INDIVIDUAL SCHEDULES IN THE EXPERIMENT WITH ME =25, MB=5 AND SECTORING MECHANISM S(1), USING TIME SAVED HEURISTIC

DAY	SCHEDULE NO.	TOTAL SCHEDULE TIME	NO.OF CUST. SERVED IN THE SCHED.	SCHED. TIME / CUST.
1	1	136.18	6	22.69
1	2	109.47	5	21.89
1	3	94.29	4	23.57
2	4	116.85	5	23.37
2	5	145.97	6	24.33
2	6	118.07	5	23.61
2	7	165.21	8	20.65
2	8	125.29	6	20.88
2	9	91.68	4	22.92
3	10	109.01	5	21.80
3	11	123.61	5	24.72
3	12	120.87	5	24.17
3	13	123.01	5	24.60
4	14	122.35	5	24.46
4	15	98.52	4	24.63
4	16	95.99	4	23.99
4	17	200.36	9	22.26
4	18	94.99	4	23.75
4	19	129.21	6	21.53
5	20	118.28	5	23.65
5	21	95.82	4	23.95
5	22	72.60	3	24.20
5	23	224.46	13	17.27
5	24	195.68	11	17.78
5	25	74.84	3	24.95
6	26	116.32	5	23.26
6	27	72.83	3	24.27
6	28	118.55	5	23.71
6	29	217.63	12	18.14
6	30	178.95	10	17.89
6	31	172.66	10	17.26