□論 文□

A Scheduling Algorithm for Fixed and Route Deviated Demand Responsive Transportation Service

固定및 逸脫路線을 대상으로한 需要感應交通「알고리즘」開發에 관한 研究

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要 約

需要感應交通體系는 승객들의 通行要求에 따라 보다 迅速하고 效率的으로 安樂하고 便利하게 經濟的으로 交通서비스를 제공하는 것이다. 특히 기존의 公共交通手段이 미치지 못하는 低密度 都市 地域의 通行需要를 만족시키는데 좋은 手段으로써 관심의 대상이 되고 있다. 즉 리무진 같은 소형차량을 利用하여 승객의 通行要請에 따라 個人的인 door－to－door 서비스를 제공하는 것이다.

本硏究는 需要感應交通體系의 代案으로서 都市 서비스에 있어서 固定·路線變更乘客 써비스에 대한 「스케쥴 알고리즘」을 開發하는데 目標를 둔바 目的函數는 Waiting time, Riding time, Scheduled vehicle 의 路線容量制限 등과 같은 乘客써비스 時間制約에 대해서 각기 個別車輛 여행과의 차를 極大化하여 보았다.

使用者中心 Sub-program과 PASS 의 두 Sub－program 으로 구성된 Simulation 模型을 活用할 경우 어떠한 都市 써비스地域에서의 固定路線 或은 變更路線 各各에 대해서 臨時的인 車輛運行의 感應式 效率 증진에 크게 기여할 수 있는 것으로 나타났다.

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I. Introduction

A concept of the Demand Responsive Transportation System (DRTS) is that the transportation service will be responded to passenger's travel requests with basic standards such as quickly, efficiently, comfortably, conveniently, and costly, etc. In particular, the DRTS is now concerned to satisfy the travel demand in the low population density urban areas where for many reasons, there are very difficulties to access the existing conventional public transportation systems. It can provide a personalized door-to-door service with respect to the passenger's trip request by using a small size vehicle like limousine type. In higher density areas, such DRTS could provide feeder service to conventional transit.

During the past several years, several alternative forms of DRTS have been implemented in order to compete with the private automobile and taxi: Dial-A-Bus, Dial-A-Ride, Call-A-Ride, Taxi-Bus, Telebus, Tele Transpo, GENIS, Maxi-Cab, Shared-Taxi, Jitneys, Subscriptions, Demand-Activated-Road-Transit (DART), and CARS (Computer Aide Routing Systems), etc. (1,3,5,6,9,19,20)

Most DRTS studies in Canada and parts of U.S.A. are more concerned to the economic feasibility studies in order to reduce the operating deficit through making greater efficiencies in system operating procedures, but yet it is inadequate due to the financing problems and poor-operating performance in the sense of technology associated with the demand responsive scheduling.

However, a great deal of research has been undertaken in the general field of transportation scheduling with fixed or known demand. But, unfortunately the demand responsive scheduling field has not involved the same amount of study.

This research is aimed at developing a scheduling algorithm for the fixed and route deviation passenger service in the urban service area as the alternative of the DRTS.

The objective function for this algorithm is intended to maximize the passenger returns in each individual vehicle tour subjected to the passenger service time constraints such as waiting time, riding time, and the link capacity constraint of the scheduled vehicle. To achieve this goal, the proposed heuristic scheduling algorithm has developed with five major sub-components which must be achieved when each scheduling has done: (1) pre-determined optimal fixed vehicle route, (2) passenger-ordering, (3) passenger assignment to the examined vehicle's provisional tour (4) checking all service and system operating constraints, and (5) evaluation of the system' s performance statistics.

A simulation model has developed as a feasible tool for the scheduling algorithm. This simulation model has structured with respect to two major sub-programs such as a user oriented sub-programs and a PASS (Parallel Acitivity Simulation Systems) source programs(30). The user oriented sub-programs are mainly contained the PASS and system's inputs, serveral optimization program(31) to determine the shortest path, and the system performance programs etc. The PASS source programs are partially adapted in order to generate the passenger list, file and then get and delete the passengers during the simulation processes. (23,30)

During the simulation run, all passengers generated in the service area assigned into the provisional vehicle tours as one-by-one basis according to the passenger's ordering list along the pre-determined fixed vehicle route with the sequential stop stations.

Provisional route deviation pick-up or delivery services occurred between two adjacent stations, and the slack time like a station and link slacks are incorporated in this scheduling algorithm.

Furthermore, the real time passengers can be incorporated into the pre-planned schedule under the only pre-assumed real time slacks such as real time waiting dealy, real time riding delay on pick-up or delivery, and some reasonable reserved real time vehicle seats. Although, the level of service for the real time passengers cannot be guaranteed because of reliability problems involved. However, without considering the real time passenger services, this scheduling algorithm has a great potential to solve the demand responsive service system problems, providing the flexible service due to pure station and pure route deviation.

Finally, the provisional vehicle tour is scheduled whenever the attempted assignment violated any one of service and vehicle constraints, the simulation time or the system queue is empty.

A considerable sensitivity analyses have taken into account various factors for the system performance evaluations with existing information data from York Mills Dial-A-Bus experiments.[21]

The outcomes of this research will give the system planners and schedulers a great impact for improvement of the demand responsive scheduling systems having fixed and route deviation passengers along the pre-determined provisional vehicle tour route in any urban service area.

II. Development of the Scheduling System

1. Model Formulation

The scheduling and routing problems for route deviation service in DRTS are fairly complicated because of their inherited complexities such as large dimensions, large number of variables, non-linear relations, uncertainties and randomness, and multi-objectives etc.

The proposed system is aimed at developing the most attractive scheduling and routing algroithm for the station and route deviation passenger's service along the basic vehicle route.

In this scheduling system, the types of passengers requested for service in the service area are classified into four catagories such that (i) pre-planned station passenger (PSP), (ii) pre-planned route deviation passenger (PRP) (iii) real time station passenger (RSP), and (iv) real time route deviation passenger (RRP).

In specific, the pre-planned trip passengers can be estimated from the more reliable trip information based upon the patronage estimation analysis, while the real time trip passengers can be estimated from the probabilistic assumptions in the real time basis after pre-planned schedule. So each passenger can make a trip as either pre-planned or real time basis.

The total passengers who request services at the event time t– can be represented as a sum of all four types of demands:

$$P(t) = P_R(t) + P_R(t)$$

$$P_R(t) = P_R^S(t) + P_R^R(t) \quad \text{.......... (1)}$$

$$P_R(t) = P_R^S(t) + P_R^R(t)$$

where

$P(t)$ = total passengers requested for services at event time t,

$P_R(t)$= pre-planned passengers requested for services at event time t,

$P_R(t)$ = real-time passengers requested for services at event time t,

$P_R^S(t)$= pre-planned station passengers occurred at event time t,

$P_R^R(t)$ = pre-planned route deviation passengers occurred at event time t,

$P_R^S(t)$= real-time station demands occurred at event time t,

$P_R^R(t)$= real time route deviation demands occurred at event time t,

Since the total passengers to be served in the service area is a constant for each scheduled time period, the propòsed objective is chosen such that the minimization of the system utilities subjected to the least acceptable service constraints due to the waiting time and the riding time, and vehicle capacity constraint on each link.

The minimization of this system utilities is equivalent to the minization of the number of vehicle tours in the scheduled time period and the total elapsed vehicle mileage.

The grobal optimization solution may not achievable in this system. However, the suboptimal solution can be obtained by finding the shortest path connecting all intermediate points between each adjacent stations in each scheduled time period.

Let the figure 1 represent the pre-planned demand density function generated in the scheduled timeperiod (O,T), and the figure 3 be its cummulative distribution function. In the figure 2, let t be the demand system time, t_i^* be the tour starting time of the vehicle tour i and x_i be the headway of tour i, then the proposed objective function which minmizes the system utilities in each scheduled tour i subjected to the waiting time, and riding time constraints for demand k in the scheduled headway x_i of the tour i; $WT_k(X_i)$ and $RT_k(X_i)$, and the link availability due to vehicle capacity constraint on each link of the scheduled tour route in the scheduled tour i can be given as follows:

$$\text{Max}\,\{F(x_i) = F_P(X_i) + F_R(X_i)\} \quad \text{.......... (2)}$$

subject to

$$WT_k(X_i) \leqslant WTC \quad , i = 1, 2, \ldots, M, K = 1, 2, \ldots, N \quad \text{.......... (3)}$$

$$RT_k(X_i) \leqslant RTC \quad , i = 1, 2, \ldots, M, K = 1, 2, \ldots, N \quad \text{.......... (4)}$$

$$LP_l(X_i) + LR_K(X_i) \leqslant VC, i=1, 2, \ldots, M, l = 2, 3, \ldots, L \quad \text{.......... (5)}$$

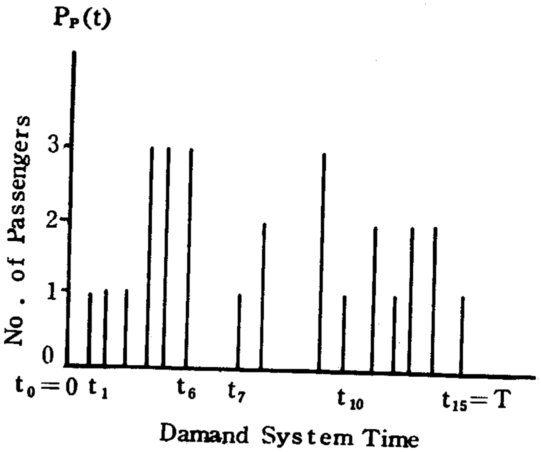


Figure 1. Pre-planned Demand Density Function

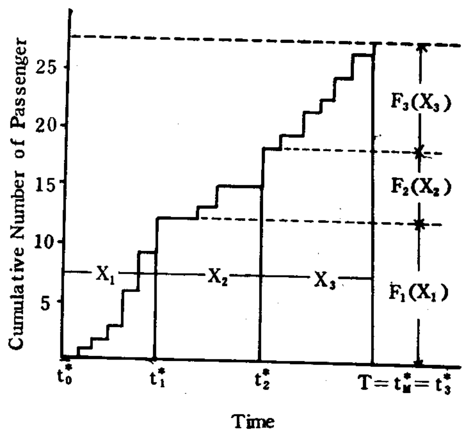


Figure 2. Cumulative Distribution of Pre-planned Demand Density

$$\sum_{i=1}^{M} X_i = T \quad \text{.......... (6)}$$

$$X_i \geqslant 0 \quad , i = 1, 2, \ldots, M \quad \text{.......... (7)}$$

where

$$F_P(X_i) = \sum_{t=t^*_{i-1}}^{t^*_i} [P^S_P(t) + P^R_P(t)] \quad \text{.......... (8)}$$

$$F_R(X_i) = \sum_{t=t^*_{i-1}}^{t^*_i} [P^S_R(t) + P^R_R(t)] \quad \text{.......... (9)}$$

WTC = the least waiting time constraint,

RTC = the least riding time constraint,

VC = the vehicle capacity constraint,

$LP_l(X_i)$ = the number of pre-planned passengers boaded on each link l in the i^{th} tour and the headway X_i,

$LR_k(X_i)$ = the number of real time passengers boaded on link l in the i^{th} tour and the headway X_i,

M = the number of tours in the scheduled time period.

On the other hand, the minimization of the total number of the vehicle tours in the scheduled time period is equivalent to maximization of the total number of served passengers.

The level of service for the real time demands $F_R(X_i)$ can not be guaranteed by using constraints (3) and (4) because of realiable trip information which is not available in pre-planning time. Hence some reasonable waiting and riding time for these real time demands can be designed by allowing time slacks in the scheduled tour.

2. Service and Other Time Constraints.

The service constraints are the major component factors to the directly affect the scheduling systems in order to provide each passenger with satisfactory service while leaving with enough slack for meeting unexpected or uncollected passengers. Since the level of service are strongly dependent on an efficient schedule which should be designed to guarantee the passenger service requests, the measurement of such service factors are fairly important to give most reliable trip information to the system users.

In this scheduling system, it is assumed that the service constraints affecting the level of service quality are classified into waiting time, riding time, and total service time.

The waiting is the time between a requested time for service being made at either a pick up station or a pick up point, and the vehicle's arrival time to pick up the passenger in the service area.

The riding time is the time between each pick up and drop off service. That is, it is the time which the passenger is boarding on the vehicle for his or her service time.

The total service time is defined as the time between a passenger's trip request for service and the delivery at the destination. This time is usually defined as waiting time plus riding time, but in general, the total time is usually greater than or euqal to the sum of waiting and riding times.

On the other hand, the time factors which are reflecting the internal process of the proposed scheduling algorithm are classified into five catagories such as the demand event time, the station time, the demand system time, the station slack, and the link slack. Brief characterizations of each of these factors follow:

(a) Demand event time

A demand event time is one which the passenger starts to wait at his or her pick up station or pick up point.

(b) Station time

The station time is defined as the travelling time required from the first (or origin) station to each station which is to provide a pick up or a drop off service on the pre-determined fixed vehicle route.

(c) Demand system time

The demand system time is the tour starting time of the vehicle's tour which arrives at the station or trip origin point at the demand event time without any delay.

By assuming zero tour decision time to start, the demand system time DT_k of demand d_k can be identified as

$$DT_k = \begin{cases} E_k - ST_i & \text{, for the station passenger } d_k \text{ at station } i, \\ E_k - (ST_i + t^*_{ik}) & \text{, for the route deviation passenger } d_k \end{cases} \qquad \text{.................................. (10)}$$

where

E_k = passenger event time of passenger d_k,
ST_i = station time of station i which is being started the travel to provide the service,
t^*_{ik} = shortest travelling time from the station i to the passenger pick-up point (or drop-off point) of passenger d_K,

Suppose we use the clock time, this system time DT_k of passenger d_k can be estimated as follows:

$$DT_k = \begin{cases} E_k - ST_i - D^*_1 & \text{, for the station passenger } d_k, \\ E_k - (ST_i + t^*_{ik}) - D^*_1 & \text{, for the route deviation passenger } d_k \end{cases} \qquad \text{................................ (11)}$$

Where DT_k, E_k, ST_i and t^*_{ik} are the same as the above and D^*_ℓ is the clock time to be made the trip decision at the station 1.

(d) Station slack

The station slack is an allowable time delay at the station on the provisional vehicle's tour without breaking any passenger's service constraints who will be picked up on dropped off at station; or in link.

By assuming the limited minimum allowable station time constraint at the station on the provisional tour, the station slack can be estimated as follows:

$$NS_{kj} = \begin{cases} SB_j - (TS_k - DT^{(1)}_j), & \text{if } TS_k \geq DT^{(1)}_j \\ \infty & \text{, otherwise} \end{cases} \qquad \text{..(12)}$$

Where

NS_{kj} = the station (or node) slack at the station j for the K^{th} ordered passenger system time,
SB_j = the minimum allowable station binding time constraint at the station j for pick up or drop off service,
TS_k = the K^{th} ordered demand system time,
$DT^{(1)}_j$ = the first requested passenger system time at the station j,

The equation (12) implies that the station slack NS_{kj} at the station j on the K^{th} ordered passenger system time can be identified as the time interval between the station binding time constraint SB_j and the time difference between the K^{th} ordered passenger system time TS_k and the first requested passenger's system time at the station j $DT_j^{(1)}$.

(e) Link slack

The link slack is an allowable time delay to permit the route deviation service on each link without violating constraints on the provisional vehicle's tour.
Such link slack LS_{kj} in the lin kj on the provisional tour 1 can be estimated by taking the minimum value among all station slacks from the station j to the last station N:

$$LS_{kj} = \underset{i \in \Omega}{\text{Min}} \, [NS_{kj}] \;, j = 2, 3, \ldots, N \qquad \Omega = \{ i \mid i = j, j+1, \ldots, N \} \qquad \text{.......... (13)}$$

Where

LS_{kj} = the link slack on the j^{th} link between two adjacent stations $j-1$ and j for $j \geqslant 2$ on the current provisional tour 1.

On the other hand, from Equation (13), we also have

$$LS_{kj} \leqslant LS_{kj+1}, j = 2, 3, \ldots (N-1). \qquad \text{.......... (14)}$$

Figure 3 and Table 1 shows us how to estimate the station and link slack on the provisional tour 1.

3. Design of Scheduling Algorithm.

At all times, each vehicle will generally have several types of passengers provisionally assigned to it, as well as some passengers already on board. So a route for each vehicle must exist for planning purpose which serves all passengers assigned to it, this is referred to as a vehicle's provisional route.

A scheduling algorithm of the demand responsive transportation system is to make a decision for which vehicle should service each passenger in such a way that keeps the sequence of pick-ups and drop-offs without violating any service and vehicle constraints. Such algorithm can be divided into two sub-techniques such as "look-ahead scheduling technique" and "provisional scheduling technique"[6, 13] The first one is to decide that the next stop of the vehicle tour is selected by the dispatcher or the computer outputs whenever a pick-up or drop-off occurred, while the second one is related to a provisional tour decision where a new demand (pick-up or drop-off) is provisionally or tentatively inserted in a pre-scheduled tour when the demand is received.

The proposed scheduling algorithm for the demand responsive transprotation service has been developed as a heuristic (i.e. computer-Aid-Heuristic) scheduling techniques according to a provisioal vehicle tour[4]Instead of multi-vehicle scheuling along the multiroutes, the proposed scheduling system has designed with a single fixed route having sequential stop stations, a single vehicle tour which is scheduled along this fixed route, and two types of pre-planned station and route deviation passengers so that a vehicle may provide either the station-stop or a door-stop service according to each passenger's trip request. So the scheduling algorithm for this type of system is strongly related to not only the scheduling itself, but also the routing problem in order to minimize the waiting and

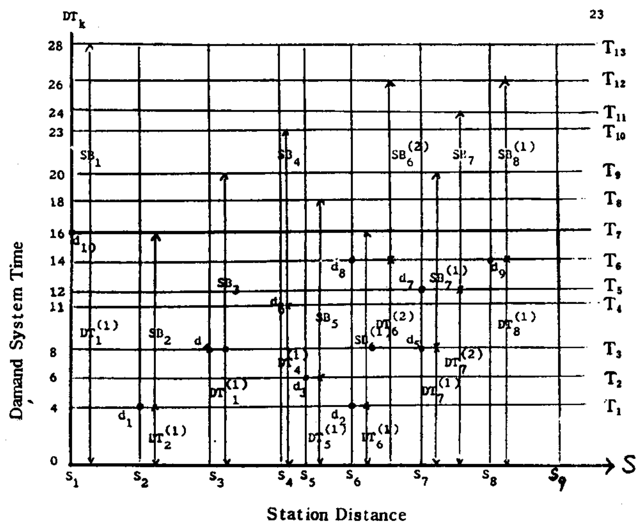


Figure 3. Graphical Representation of Station Slacks.

S_i $= i^{th}$ station

$DT_j^{(1)}$ = the i^{th} intermediate passenger's system time at the station j

$SB_j(1)$ = station binding time at the station j for the 1^{th} passenger's trip request,

T_1 = Tour starting order, $1 = 1, 2, \ldots < \infty$

Table 1. Computation of Station and Link Slacks for Each Examined Provisional Tour

Demand Order (k)	Demand Type (d_k)	Pick up Station	Demand System Time (TS_k)	Tour Delay (TD_k)	Station Binding Const. (SB)	Tour Order	S_1 (1) DT_1	S_1 NS_1	S_2 (1) DT_2	S_2 NS_2	S_2 LS_2	S_3 (1) DT_3	S_3 NS_3	S_3 LS_3	S_4 (1) DT_4	S_4 NS_4	S_4 LS_4	S_5 (1) DT_5	S_5 NS_5	S_5 LS_5	S_6 (1) DT_6	S_6 NS_6	S_6 LS_6	S_7 (1) DT_7	S_7 NS_7	S_7 LS_7	S_8 (1) DT_8	S_8 NS_8	S_8 LS_8	S_9 (1) DT_9	S_9 NS_9
1	d_1	S_2	4	0	12	T_1			4	12	12			12			12			12	4	12	12								
2	d_2	S_6	4	0	12																										
3	d_3	S_5	6	2	12	T_2			4	10	10			10			10	6	12	10	4	10	10								
4	d_4	S_3	8	2	12	T_3			4	8	8	8	12	8			8	6	10	8	4	8	8	8	12	12					
5	d_5	S_7	8	2	12																										
6	d_6	S_4	11	3	12	T_4			4	5	5	8	9	5	11	12	5	6	7	5	4	5	5	8	9	9					
7	d_7	S_7	12	1	12	T_5			4	4	4	8	8	4	11	11	4	6	6	4	4	4	4	8	8	8					
8	d_8	S_6	14	2	12	T_6			4	2	2	8	6	2	11	9	2	6	4	2	4	2	2	8	6	6	14	12	12		
9	d_9	S_8	14	2	12																										
10	d_{10}	S_1	16	2	12	T_7	16	12	4	0	0	8	4	0	11	7	0	6	2	0	4	0	0	8	4	4	14	10	10		
11			18	2	12	T_8	16	10	4	-2	-2	8	2	-2	11	5	-2	6	0	-2	4	-2	-2	8	2	2	14	8	8		

the travelling times for the better level of service. Thus, this scheduling has essentially two basic routes: (i) the pre-determined fixed route, and (ii) deviation route. So various types of services can be provided in such a way; many-to-one, one-to-many, many-to-few, few-to-many, or many-to-many on the passenger's trip requests. Furthermore, by designing the scheduling algorithm with long lead time and trip repetitiveness, the real time passengers can be partially collected by the pre-planned vehicle tour with pre-planned passengers. So the scheduling algorithm assigns each passenger into the planned vehicle tour, keeping the one-by-one basis, providing the provisional route deviation service, and check and control all the passenger service and vehicle capacity constraints before determining the vehicle schedule, and then print out the system performance at each tour schedule. Such vehicle schedule is determined when any one of service or vehicle capacity constraints is violated in the scheduling process.

With all the above descriptions in mind, the proposed heuristic scheduling algorithm has developed with five major sub-components which must be achieved when each scheduling has been done.

(a) pre-determined optimal vehicle route (Fixed Route).
(b) passenger's ordering.
(c) passenger assignment to each examined vehicle's provisional tour.
(d) checking service constraints and system operating constraints for the goal reach.
(e) evaluation of the system performance statistics for each scheduled vehicle tour and overall tours.

3.1. Determination of the Vehicle's Fixed Route

A service area chosen in this scheduling system is selected from the York Mills Go-Dal-A-Bus DRTS[18, 28] service area. This service area has three subzones, and each zone has focal points representing 9 major stop stations on the Dial-A-Bus route.

Considering such pre-determined vehicle route as a network, station as focal points (or nodes), and subroutes between adjacent stations as link, the system scheduler can be classified all pre-planned passengers into the pre-planned station passengers who want to be picked up or dropped off at any one of the stations on this vehicle route, and the pre-planned route deviation passengers who request the deviation service from this route. So, the pick-up and delivery points of route deviation passengers are considered as intermediate nodes. Since the intermediate nodes are not usually on the fixed route, and are located off the route, the final service area is selected by a 4 square miles-rectangular region along the pre-fixed route in order to provide a flexible service for the station passengers, the route deviation passengers, and both.

3.2 Pre-planned Passenger's Ordering

All generated passengers in the service area have the following three basic informations associated with the pre-determined fixed vehicle route having the identified station numbers: for the pre-planned station passengers, the demand event time, the passengers' pick-up or drop-off stations, while for the pre-planned route deviation passengers, the demand event time, pick-up or drop-off co-ordinates. Since it is assumed that the station numbers are listed according to the vehicle's arriving order along the pre-determined route, each station time is actually measured as travelling time from the vehicle origin (i.e. first station) to each specified station.

In order to assign each passenger into the vehicle's provisional tour determined by the order of the demand system time as one-by-one basis, all passengers must be arranged in ascending order according to the passenger system time which is defined as the time interval between the passenger desired event time and the actual vehicle arrival time to the passenger's pick-up station or pick-up point to serve without considering any delay involved.

In case which has many same demand system times, the ordering is assumed to be done as follows; for the station passengers, the ordering has done with respect to the station order, while for the route deviation passengers who have the same system times between adjacent stations, the ordering is done with respect to the intermdiate ascending node order under the given trip direction.

As shown in table 2 since the station passengers 1 and 13 have the same system time, the demand order should be listed as 1, 13 (i.e. d_1 and d_{13}).

For the station and route deviation passengers 4 and 8 between two adjacent stations 3 and 4, the demand order should be listed as 3 and 8 order (i.e. d_3 and d_8). Similarly, all station and route deviation passengers designated from 1 to 18 can be listed in ascending order of the demand system time, (DT_k).

3.3. Passenger Assignment to Each Examined Vehicle's Provisional Tour

In this scheduling system, all passengers will be assigned one-by-one basis into each examined vehicle's provisional tour which starts at his or her system time.

3.3.1 Trip Assignment for the Pre-Planned Station Passengers to the Vehicle Tour

Let us see how the pre-planned station passengers can be assigned to each examined provisional vehicle tour until the final scheduled tour decides. Table 3 shows the trip information which rearranged passenger trip requests with respect to the passenger system time.

Table 4 shows the trip assignment with information from table 3 to the examined provisional tour schedules until the final scheduled tour T_7 is obtained. The station slack, link slack and the link capacity constraints are also checked per each examined schedule.

The figure 4 shows the currently examined vehicle tours for the purely pre-planned station passengers which are rearranged with respect to the demand system time and the fixed provisional route having sequentional stop-stations.

3.3.2 Trip Assignment for the Pre-Planned Route Deviation Passengers to the Vehicle Tour

Since there are many basic routes and many route deviation passengers between any adjacent stations along the pre-planned vehicle tour route, the trip assignment for the route deviation passenger is not simple determined in order to guarantee the current and future passengers service requests. Because of variable routing problems are involved, one of the trivial approaches must take into account the determination of the optimal feasible route (i.e. shortest route) between successive stations having the many route deviation service points. This is directly related to the task as how to increase the vehicle productivity without breaking any service constraints. Since the

Table 2. Pre-planned Passenger's (PSP & PRP) Trip Information

Demand Numbers	Demand O/D		Demand Event Time (E_k)	Station		Time for R.D. (t^*_{ik})	Demand System Time (DT_k)
	Pick up	Drop off		ID	Time (ST_k)		
1	d_1		0	S_1	0		0
2	d_{13}		0	S_1	0		0
3	d_2		7	S_2	3		4
4		d_3	11.5			2.5	6
5	d_4		14	S_3	6		8
6		d_8	14	S_3	6		8
7		d_5	18			2.0	10
8	d_{10}		23			5.0	12
9	d_{12}		24	S_4	10		14
10		d_{14}	27			2.0	16
11		d_9	29	S_5	12		17
12	d_{15}		29	S_5	12		17
13		d_6	31.5			1.5	18
14	d_7		34			3.0	19
15		d_{11}	38			5.0	21
16	d_{16}		41			6.0	23
17		d_{17}	42	S_6	16		26
18		d_{18}	43			2.0	30

Table 3 Passenger's Trip Information Sheet

Demand Number (K)	Stations		Demand System Time (DT_k)	Station Binding Time (SB)
	Pick up	Drop off		
1	2	4	4	12
2	6	8	4	12
3	5	7	6	12
4	3	6	8	12
5	7	8	8	12
6	4	7	11	12
7	7	8	12	12
8	6	8	14	12
9	1	4	15	12
10	5	7	17	12

basic advantages of the route deviation services over the pre-determined fixed route are to increase the vehicle productivity providing the flexible door-to-door service, the most important task is to find the optimal feasible route in order to minimize the travel time and its associated costs when the

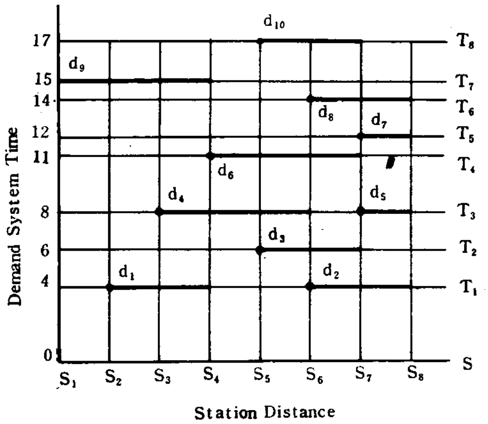


Figure 4 Examined Vehicle Tour with the Purely Pre-planned Station Passengers.

Table4. Trip Assignment for the Pre-planned Station Passengers and Provisional Vehicle Tour Schedule

Demand Number	Tour Station Time (DT)	Tour Delay (TD)	S_1		→ L_2		→ S_2		→ L_3		→ S_3		→ L_4		→ S_4		→ L_5		→ S_5		→ L_6		→ S_6		→ L_7		→ S_7		→ L_8		→ S_8	
			PD	NS_1	LS_2	LC_2	PD	NS_2	LS_3	LC_3	PD	NS_3	LS_4	LC_4	PD	NS_4	LS_5	LC_5	PD	NS_5	LS_6	LC_6	PD	NS_6	LS_7	LC_7	PD	NS_7	LS_8	LC_8	PD	NS_8
1	4	0			12		P	12	12	1			12	1	d	12																
2	4	0			12			12	12				12			12	12				12		P	12	12	1			12	1	d	12
3	6	2			10			10	10				10			10	10		p	12	10	1		10	10	2	P	12	10			10
4	8	2			8			8	8		P	12	8	2		8	8	1		10	8	2	d	8	8			10	8			10
5	8	2			8			8	8			12	8			8	8			10	8			8	8		P	10	8	2	d	8
6	11	3			5			5	5			9	5		P	5	5	2		7	5	3		5	5	3	d	7	5			5
7	12	1			4			4	4			8	4			4	4			6	4			4	4		P	6	4	3	d	4
8	14	2			2			2	2			6	2			2	2			4	2		P	2	2	4		4	2	4	d	2
9	15	1	P	12	1	1		1	1	2		5	1	3	d	1	1			3	1			1	1			3	1			1
10	17	2		10	-1			-1	-1			3	-1			-1	-1		P	1	-1	4		-1	-1	5	d	11	-1			-1

Note: $\bar{T}_{.}$: 1^{th} provisional tour

TS_k : k^{th} demand system time

NS_j : station slack represented without the subscript k from the original NS_{kj}

T_7 : Finally scheduled provisional vehicle tour with passenger trip information in Table 3.

NS_j = station or node slack at the station j

LS_i = link slack on the link i

LC_i = link trip volume on the link i

single vehicle is scheduled. So the question arising is what kind of vehicle routing policy should be taken? How many intermediate nodes can be inserted into the provisional tour?

In order to minimize the travel time affecting the level of service and vehicle utilization, the vehicle route should be determined optimally by the proper optimization routine. Suppose the current provisional tour is scheduled to pick up the station passenger at the station i and now the vehicle is going to trip to insert the deviation pick-up or drop-off nodes which lies between stations i and i+1.

Then the scheduling purpose is to assign as many intermediate nodes as possible to the current provisional vehicle tour without breaking any service time and capacity constraints. To insert such nodes feasible and optimally before the next new provisional tour is scheduled, many optimization techniques can be applied in order to find the shortest route connecting two adjacent stations i and $i+1$, and intermediated nodes.

For example, let us consider the figure 5 which has four intermediate nodes between two adjacent stations A and B. Then the system scheduler's purpose is to find the shortest path to connect all inserted stop nodes between A and B.

T.C. Hu's algorithm (31), Narahari Pandit's shortest route problem (32), Branch and Bound algorithm, and other optimization techniques can be applied to find this shortest path. In this paper, Hu's revised matrix algorithm was applied, and the shortest path connecting stations A and B is determined as ACEDFB.

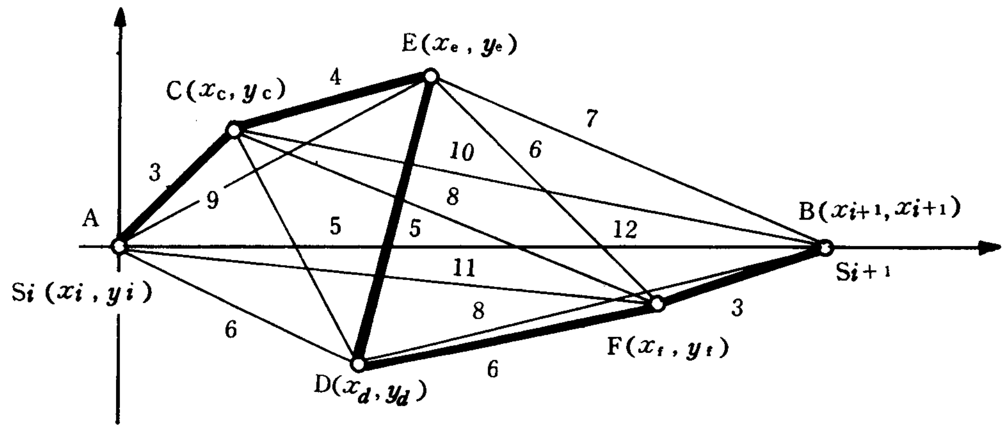


Figure 5 . Subnetwork with Four Intermediate Nodes Between Two Adjacent Station A and B .

However, this optimal route may or may not be a feasible route because it may violate the service time constraints by travelling this route, and the vehicle capacity constraint. In what follows, the feasible assignment procedure for the route deviation passengers to the current provisional vehicle tour is given as follows by using the optimal vehicle routing option under the ordered pre-planed demand list:

(i) Pick up the first ordered routed deviation service node,

(ii) determine the shortest path connecting two adjacent station i and $i+1$, or deviation stop node,

(iii) check the all-service constraints and vehicle capacity whether or not it is violated, by applying the node insertion criteria (4). If no constraint violates, then go to step (iv), otherwise, go to step (v).

(iv) If there are more intermediate nodes, then add the next ordered route deviation service node, and then go step (ii).

(v) determine the insertion nodes and the path, and compute a new provisional tour starting time and other times due to tour delay, waiting delay and travel delay, etc.

This trip assignment is to determine the feasible assignment by using the optimal sequential vehicle routing option and the node insertion criteria which can be incorporated into sub-routine CONTRB. However, this option requires more computer storage and re-determines the vehicle route whenever the insertion happened. This may not be economical, but the best way.

Next, in order to see how the station and the link delays can be affected the provisional tour, we see the Figure 6. As shown in this Figure, the station delay at the station *i* is the delay caused by the service provided at this station. This station delay is usually occurred because of the gap between earlier vehicle's arrival time and the requested demand event time. However, in this Figure, the gap is relaxed because of the next demand event time. So the station delay for the demand d_7 with the required demand event time E_7 at the station i is given by D^S_{i7} and this D^S_{i7} is also represented the time interval between two successive tours T_5 and T_6.

The link delay on the link *i* between two stations *i*-1 and *i* is the time delay caussed by the route deviation services provided between these stations. In the Figure 6, the link delay for the demand d_6 on the link *i* is given by D^R_{i6}. So the current provisional tour T_4 must be delayed up to the link delay D^R_{i6} in order to make a new provisional tour T_5. Because of the above station and link delays, the tour delay at the station *i* on the current scheduled provisional tour T_4 can be represented by $D^R_{i6} + D^S_{i7}$.

On the other hand Figure 6 shows that the link delays D^R_{32}, D^R_{43}, D^R_{44}, and D^R_{i6} are caused by previously assigned route-deviation demands d_2, d_3, d_4, and d_6. D^S_{45} and D^S_{i7} show the station delays caused by station demand d_5 and d_7. G_k is the gap (or time interval) between the previous provisional vehicle tour arriving time and the route-deviation demand (d_k) event time E_k. From the above, the total tour delay at the station *i*, TD_i can be computed as the sum of all tour delays before station i with its own station delay D^S_{i7} that is,

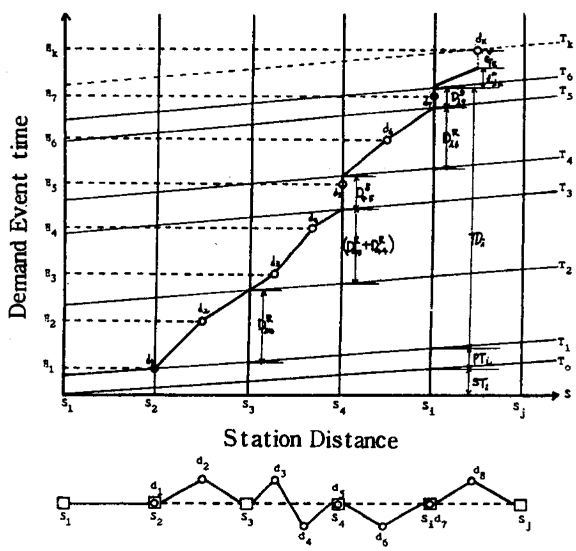


Figure 6. Tour Delay Affecting the Provisional Tour

$$TD_i = D^R_{32} + D^R_{43} + D^R_{44} + D^S_{45} + D^R_{i6} + D^S_{i7} \quad (15)$$

The provisional tour arriving time TA_k for the route-deviation demand d_k can be computed as the sum of the station time, ST_i, the provisional tour starting time PT_i, and total tour delays of the station i, and travelling time t^*_{ik} between the station i and route-deviation demand d'_ks pick up cr drop off point :

$$TA_k = ST_i + PT_i + TD_i + t^*_{ik} \quad (16)$$

Consequently, G_k can be represented as follows :

$$G_k = E_k - TA_k \quad (17)$$

When assuming zero decision time to start the tour, the demand system time for the route-deviation demand d_k between two adjacent stations i and $i+1$ is

$$DT_k = E_k - (ST_i + t^*_{ik}). \quad (18)$$

From the E_qs (16) – (18), the gap G_k is given as follows:

$$G_k = DT_k - (PT_i + TD_i). \quad (19)$$

3.3.3. Trip Assignment of Real Time Passengers along the Provisional Tour

3.3.3.1. Real Time Passengers and Real Time Slacks

The pre-planned station and route deviation passengers within the scheduling planning periced [O,T] can be collected from the existing trip data in the service area. But the point is that we don't know what the real time passengers arise at the real time situation. So some reasonable assumptions must be taken into account the real time passenger estimation (23).

In our scheduling systems, the real time passenger is defined as the passenger who asks his trip service after pre-planned schedule, and such real time passengers are incorporated with the pre-planned scheduling algorithm by allowing some probabilities of the pre-planned pssengers, PSP and PRP. (28). That is, they are $\alpha\%$ of PSP for RSP, and $\beta\%$ of PRP for RRP.

In this scheduling system, the real time slacks are classified as a real time waiting delay, riding delay, and vehicle seat slack. They are generally uncertain and unpredictable to identify. So, by adapting the hypothical real time passenger density function which may not be same as the actual case, the expected real time waiting slacks at the station or on the link of the provisional vehicle's tour can be calculated as:

$$RTSW_i = D_1 * RSP * (CPRS_{i+1} - CPRS_i),\ i = 1,2,...,(2N-1) \quad (20)$$

and

$$RTRW_i = D_2 * RRP * (CPRR_i - CPRR_{i-1}),\ i = 2,3,..,2N. \quad (21)$$

Where , $RTSW_i$ = real time station waiting slack at the station i

$RTRW_i$ = real time route deviation waiting slack on the link i

$\bar{D}_i$ = mean delay per real time station passenger,

D_2 = mean delay per real time route deviation passenger,

$CPRS_i$ = cumulative density of the real time station passenger at the station i,

$CTRR_i$ = cumulative density of the real time route deviation passenger in each link i.

For the $CPRS_i$ and $CPRR_i$, $CPRS_i$ is generated from the poisson random number generator with the mean arrival rate 3. $\bar{CPRR}_i$ is also generated by taking a psedo-random number such that 20 * RANF (5).

Similarly, the real time riding slacks for each station and route deviation passengers can be estimated as:

$RTSR_i = TTC - RTSW_i$, $RTRR_i = TTC - RTRW_i$ . . . . (22)

where $RTSR_i$ and $RTPR_i$ represent the real time station riding delay at station i and real time link riding delay in link i for the deviation service, and TTC is the total allowable travel time constraint.

On the other hand, without loss of generality, one can estimate the real time waiting, and riding slacks by taking the average value between each two types of slacks.

The real time vehicle slack is identified as the reserved seat numbers or available empty seat numbers for both types of real time passengers to be assessed to the provisional vehicle tour wothout violating the vehicle maximum capacity constraint. So the average real time vehicle seat number can be estimated by subtracting the real time slack from the vehicle capacity. But, even if we can estimate the real time pssengers under some assumptions, the assignment of such real time passengers into the pre-planned vehicle operation is not easy as far as the reliability is concerned. Because of time varying and dynamic behavior in the real time passengers, it is really difficult to meet each passenger's service guarantee. Yet, no existing demand responsive transportation scheduling system satisfies efficiently for the real time passenger's services.

3.3.3.2. Trip Assignment of the Real Time Passengers

On the current implementation of the scheduling algorithm, there is nothing to guarantee the level of service for the real time passenger, but it is considered under only non-violation constraints for the pre-planned passenger service in order to assign the real time passenger into the provisional vehicle tour.

Suppose that the real time vehicle slack is given as a reserved seat number; RSEAT, then the insertion criteria of the real time route deviation passengers to the provisional tour is depending upon the following rule:

Let RRP_j be the real time route deviation passengers generated in link j, then

if $RRP_j \leq LS_j$, then RRP_j can be inserted.

if $RRP_j > LS_j$, then terminate. . . . . (23)

For the real time station passenger assignment to the provisional vehicle tour, it must statisfy the station slack generated at the station j and also further down link slack.

It is also considered a re-assignment passenger constraint for exceeding the vehicle capacity caused by real time passengers at some portion of the per-determined route.

The scheduling algorithm must need to control in order to determine the actual real time passengers to accommodate at this station or in this link such that:

$$P_j(r_\alpha, r_b) = \begin{cases} \text{Min [RSEAT, AARP}_j], & \text{if AARP}_j > \text{RSEAT} \\ \text{RSEAT} & \text{, if AARP}_j < \text{RSEAT} \end{cases} \quad \text{(24)}$$

where $P_j(r_\alpha, r_b)$ is the real time passenger arised at station j or in link j whose origin and destination point are r_α and r_b, respectively, and $AARP_j$ represents the actual accommodated real time passenger at each station or in link j such that:

$$AARP_j = \sum_{\alpha=1}^{n-1} \sum_{\beta=\alpha+1}^{n} \left\{ A_{r_\alpha, r_\beta} - b_{r_\alpha, r_{\alpha+1}} \right\} \quad \text{(25)}$$

where n is an end node on Route R, A_{r_α, r_β}: pick-up real time passengers at node r_α who is willing to travel from r_α to r_β, and $b_{r_\alpha, r_{\alpha+1}}$ drop-off passengers who picked up at node r_α, but drop-off at node $r_{\alpha+1}$.

Unfortunately, such control program is not applied to our scheduling algorithm because of internal complexities during the scheduling process. The implementation of our current scheduling algorithm can be accepted the above criteria to re-assign the real time passengers to the provisional tour without breaking the service constraints.

3.4. Checking Service Constraints and System Operating Constraints for the Goal Reach

After each passenger assignment, the service constraint and the system operating characteristics are checked. If any one of such constraints are violated or reached, then the provisional tour assignment task will be terminated, and the tour starting decision time, defined as the scheduled tour time after the assignment termination will be listed in the pre-planned schedule.

3.5. Evaluation of the System Performance Statistics for Each Scheduled Vehicle Tour and the Expected Average Information Over All Tours

At each assignment termination, a measure of service factor affecting the level of service, and other system performance factors are evaluated. Suppose the current provisional scheduled tour does not completely serve passengers, i.e. more passenger assignment required after each assignment, then a new provisional tour will be generated for the following passenger assignments until no more assignments are required. So the final scheduling can be done by such feedback processes or iteration processes.

III. Computer Simulation Program

1. Simulation Program Structure

A simulation Program Consists of the following four major components: (1) Initialize assembles, (2) passenger generation, (3) scheduling of sub-vehicle's tour, (4) Evaluation of the system performance.

1.1. Initialize Assembles

Subroutine PINITAL is a first executable statement of the program and initializes all variables in COMMON PASS/ and other internal PASS variables.[30]

The COMMON/PASS/ITEM (16), KONST (16), KTEST (16), LARNK (25), LSIZE (25) MONIT, MAXT, LUKBAK COMMON block is used by all PASS routines, and is a convenient method for dynamically updating information in the system.

Subroutine SINPUT and SINIT L initialize all other variables in COMMON Blocks, and identify necessary parameters to use in the simulation model. SINPUT's inputs are (1) simulation run number, and travel time constraints, (2) total number of station for one travel direction (i.e. east bound trip), (3) vehicle number, vehicle capacity, and average speed, (4) least waiting and riding time factor, (5) fare, (6) average waiting delay for real time station and route deviation passengers, (7) service area size, (8) DEMGEN's imputs etc.

The outputs from SINPUT and SINITL are (1) effective speed, (2) guaranteed waiting time and riding time delay, WTC and TTC. (3) Station and link travel time between two adjacent stations, (4) accommodated passengers by type.

IPRINT routine is to printout all necessary inputs used in the simulation.

1.2. Passenger Generation

Subroutine DEMGEN has two main functions which generate the passenger or file all passengers into the LIST N before the provisional tour starts.

Inputs for DEMGEN are (1) percentage of passengers by type, (2) percentage of the East and West bounded traveling passengers. The outputs from DEMGEN are (1) the number of four type's passenger generated, (2) East and West bounded trip passengers, (3) Filing all passengers generated in ascending order according to the demand system time, and then storing them into the LIST N.

1.3. Scheduling of Sub-vehicle's Tour

From the results of sub-routine DEMGEN, all pre-planned passengers are stored in LIST 1 as ascending order according to the passenger system time. The passenger assignment to each sub-vehicle is based upon the first order-first allocation priority. Each sub-vehicle's tour is determined when any violation happens from one-by-one passenger assignment. In this case, the scheduling algorithm should take the following steps:

(1) Test whether the current sub-vehicle's tour having the current passengers can be scheduled. If scheduled, then go to step (7). Otherwise, go to step (2).
(2) Get one passenger from the LIST 1.
(3) Determine whether or not the selected passenger is a candidate to schedule the current sub-vehicle's tour. If selected, go to step (4). Otherwise, go to step (7).
(4) Determine what type of passenger should be, and then test whether or not this passenger allocation to the current sub-vehicle's tour is violated any service and vehicle's constraints. If not, go to step (5). Otherwise, go to step (7).

(5) File the determined tour information from the LIST 1 to the LIST 2.
(6) Get the next ordered passenger, and then, go to the step (3).
(7) Set up the new tour starting time, and delete passenger information from LIST 2, one-by-one, and then compute the system queue performance statistics of the current sub-vehicle's tour. Then, calculating all necessary values for a new (next) sub-vehicle's tour.
(8) Test whether or not all passengers stored in LIST 1 are assigned to the all each sub-vehicle's tours. If assigned go to step (9). Otherwise, go to step (1).
(9) Evaluate the system performance and printout the performance statistics.

In scheduling each sub-vehicle's tour, sub-routiness CONTRA and CONTRB together their supporting sub-routines RTDGEN and TTMDLY play on the major role. Sub-routines CONTRA and CONTRB are the assignment sub-routines associated with the pre-planned station passengers and route deviation passengers with allowed real time passengers. These routines assign each passenger into each separated vehicle tour.

The real time passengers that may be collected by each separate vehicle's tour are generated by the sub-routine RTDGEN. This routine is to estimate the number of real time station or route deviation passengers and the real time slacks: (i) real time waiting delay, (ii) real time riding delay and (iii) real time vehicle slack which affect the pre-planned tour assignment.

By calling the RTDGEN, sub-routine CONTRA and CONTRB get the information of the real time passengers are control the real time passenger asignment as whether the estimated real time passenger can be allocated to the current vehicle tour without violating the current restricted service constraints and vehicle constraint. Whenever no violations by assigning these real time passengers occur, CONTRA and CONTRB assign the real time passenger into the current tour, and check and recalculate the slack times and other constraints for the next tour. On the other hand, by calling TTMDLY routine, the control sub-routine CONTRA and CONTRB can obtain the travel delays of all assigned passengers.

The necessary inputs for RTDGEN and TTMDLY are provided by using COMMON statements and other event sub-routines. CONTRA and CONTRB get all necessary information to control the vehicle scheduling and passenger assignment by using the COMMON Blocks together with the PASS COMMON Block, i.e. COMMON/PASS/. Sub-routine FILASC (2) is used for filing the information from LIST 1 into the LIST 2 according to the passenger system time order. Sub-routine PROCE 1 is called in the main program for the purpose of providing the system queue performance calculation in each separate vehicle tour and also deletes the passenger's information from the LIST 2 one by one. Finally the entry routine NEWTOR is needed to provide the necessary information for the new sub-vehicle's tour..

1.4. Evaluation of the System Performance and Printout the Performance Statistics

A sub-routine PRLIST (4) is the routine in PASS. It is used for waiting a specific queue during the simulation and allows the printing out the specific tour information statistics which are stored in the LIST 4 and the current simulated time.

Sub-routine PROCE 2 is a processing routine and is used for deleting the tour information from the LIST 4 and computes the necessary tour performance information for the sub-routine STAOUT. The sub-routine STAOUT is to calculate the system performance statistics with the information from the PROCE 2 and printout them. After printing out all necessary performance statistics, the simulation algorithm is to check whether or not the day operation is over. If not so, then take the next planning trip information with some new input variables over the existing simulation inputs, and then go back to the sub-routine PINITAL in order to consider the next provisional tour schedule.

2. Program Flowchart

The major program flowchart of the simulation model is shown in Figure 7 without presenting all detailed sub-program's flowchart.

IV. Sensitivity Analysis of the Scheduling System's Performance

The proposed scheduling system was developed under the various combinations of four type's passengers generated in the service area and the scheduling algorithm was also developed for a complete range of demand responsive service from "Many-to-One or One-to-Many" to "Many-to-Many" service with fulfilling the various constraints. Futhermore, the pre-planned station passengers can be served with a small link slack and empty seats of the vehicle, while the.pre-planned route deviation passenger can be served not only with larger link slacks for insertion of the deviation passenger's origin or destination, but also with empty seat numbers in the vehicle.

So the series of simulation experiments are to evaluate the system's performance by the scheduling algorithm, and also to investigate the many possible effects based upon the different characteristics of the route deviation service.

In what follows, the various simulation experiments are analysized to investigate possiblities of DRTS for any urban transportation service areas.

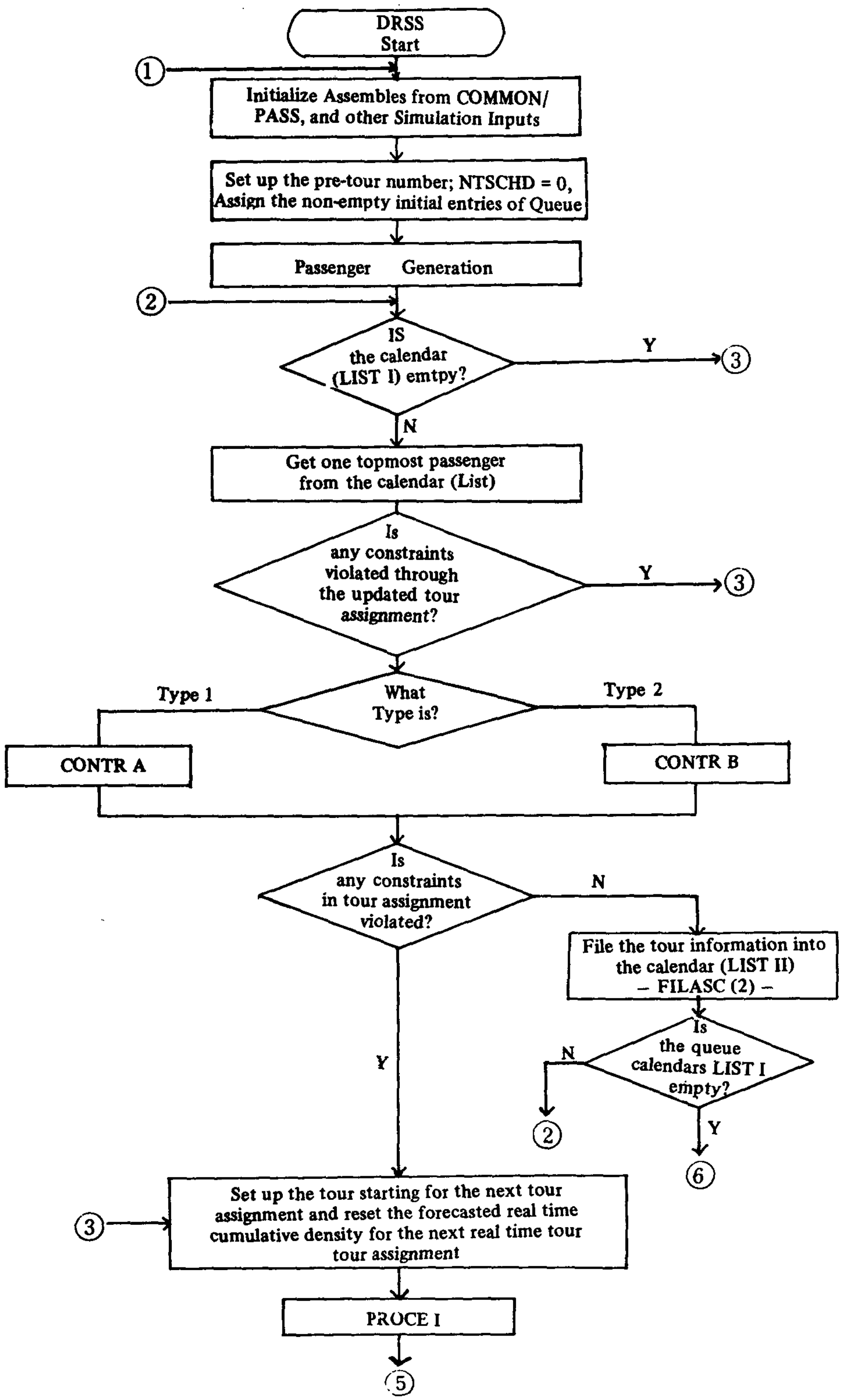
1. Day Scheduling Experiment

Figure 8 shows a typical day vehicle scheduling experiment. This figure shows that a higher density of dispatches occurs at times (i.e. peak hours) of higher passengers density as expected. However, the vehicle loads are not strictly greater during these times while the average vehicle loads higher than any other times. These are because each individual vehicle schedule is a complicated function of passenger combinations, passenger-trip requests due to their times concerned, guaranteed passenger service time constraints, and vehicle seat capacity, etc.

The Table 5 is summerized some important estimated factors from this experiments.

2. Vehicle Productivity

Figure 9 shows the vehicle productivity vs. the size of the service area. This figure indicates that


DRSS
Start
①
Initialize Assembles from COMMON/ PASS, and other Simulation Inputs
Set up the pre-tour number; NTSCHD = 0, Assign the non-empty initial entries of Queue
Passenger Generation
②
IS the calendar (LIST I) emtpy?
Y
③
N
Get one topmost passenger from the calendar (List)
Is any constraints violated through the updated tour assignment?
Y
③
What Type is?
Type 1
Type 2
CONTR A
CONTR B
Is any constraints in tour assignment violated?
N
File the tour information into the calendar (LIST II) – FILASC (2) –
Is the queue calendars LIST I empty?
N
②
Y
⑥
Y
③
Set up the tour starting for the next tour assignment and reset the forecasted real time cumulative density for the next real time tour tour assignment
PROCE I
⑤

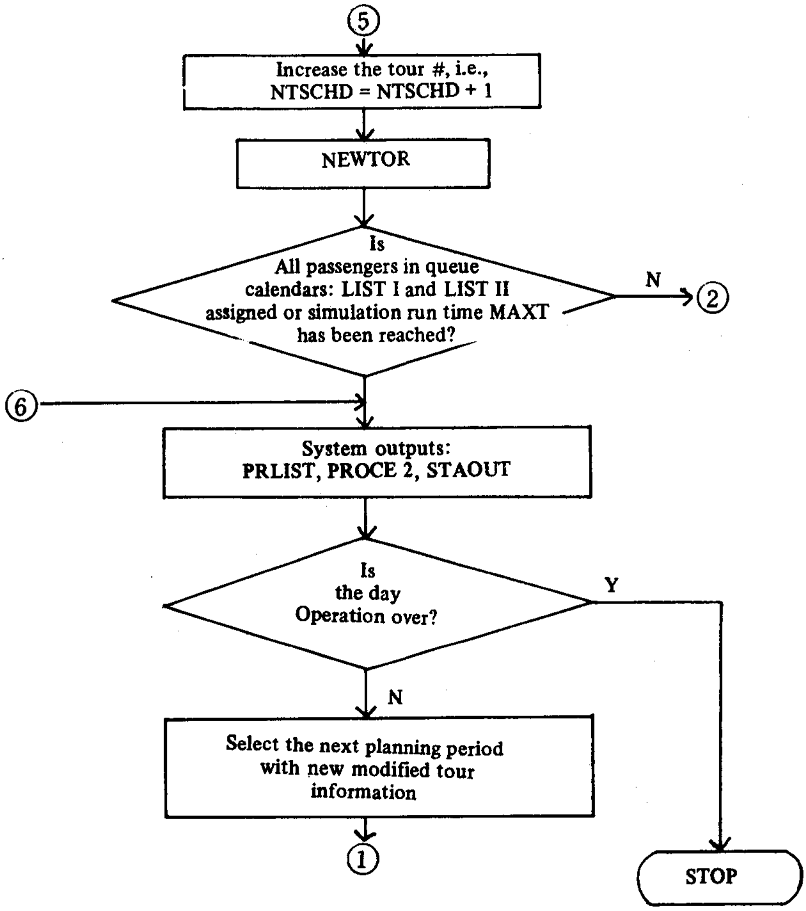


Figure 7. The Basic Flowchart of the Program

Table 5. Simulated Day Vehicle Scheduling Experiment.

	Time Period	Average Headway	Accommodated Passengers	Number of dispatched vehicles	Vehicle* Productivity	
Peak	A.M. 7:00 ~ 9:59	6.40 min.	416	23	18.09	** (12.38)
	P.M. 4:00 ~ 6:59	6.27 min.	484	26	18.62	
off-peak	A.M. 10:00 ~ 11:59	20.67 min.	83	6	13.83	** (8.63)
	P.M. 12:00 ~ 3:59 7:00 ~ 10:30	20.08 min	267	23	11.61	
Overall period		–	1250	78	16.03	** (10.27)

* : Vehicle productivity = All mixed passengers/No. dispatched Veh.

**: Results from the York Mills Survey data. (21, 28)

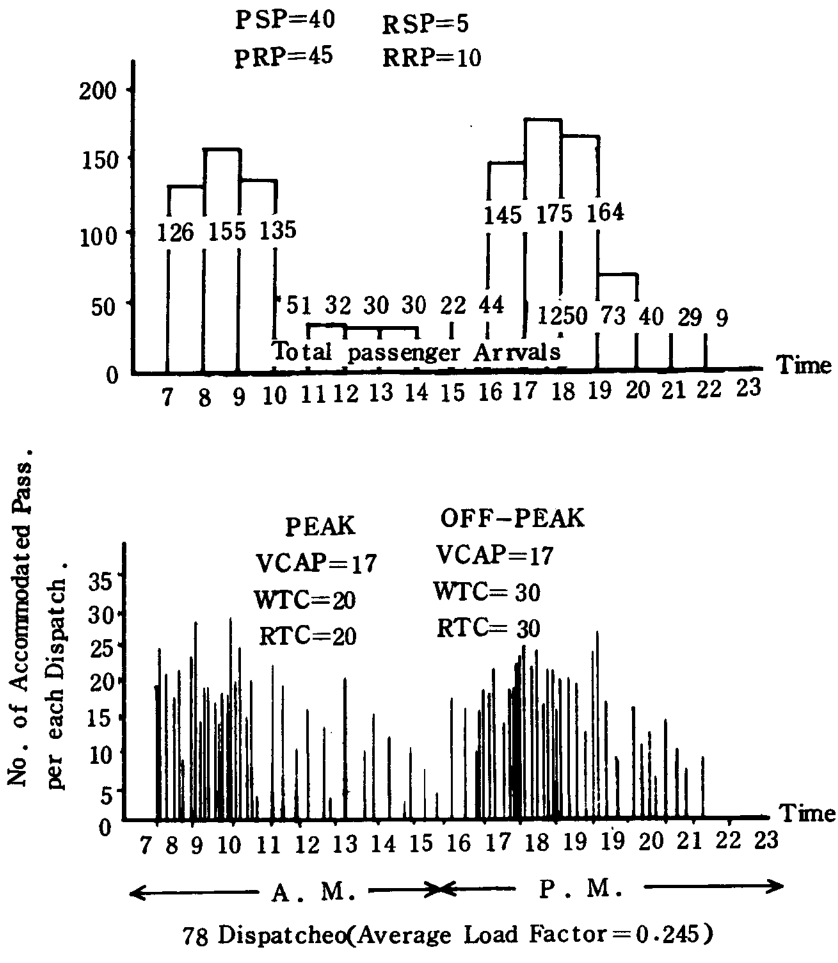


Figure 8. Day Scheduling Experiments

the vehicle productivity increases nonlinearly with increasing the size of the service area in general. It also shows that the lower percentage for the pre-planned route deviation service provides higher productivity with increasing the size of the service area.

Figure 10 shows that the vehicle productivity increases with increasing the passenger trips in the given service area. For example, when the pure many-to-many pre-planned route deviation service (i.e. PRP = 100%) was provided, and the passenger trips increased from 50 to 200, the vehicle productivity increased up to about 24%. Similarly, when the pure pre-planned station passenger service (i.e. PRP = 0%) was provided, and the passenger trips increased from 50 to 200, the vehicle productivity increased drastically about 168%.

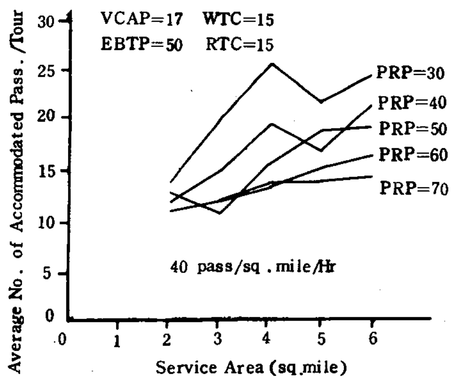


Figure 9. Vehicle Productivity vs. Service Area.

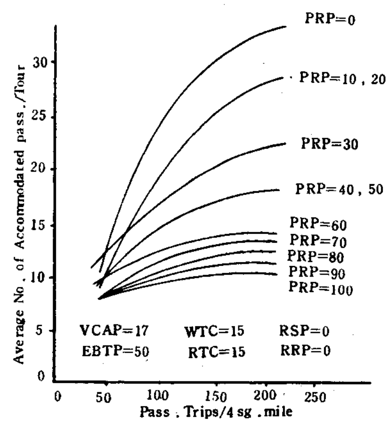


Figure 10. Vehicle Productivity vs. Trip Volume.

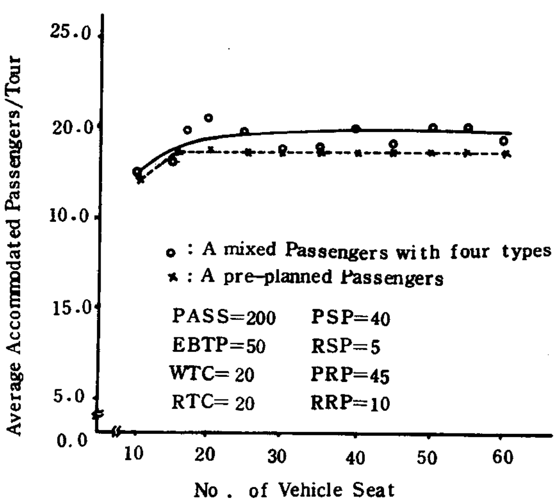


Figure 11. Vehicle Productivity vs. Vehicle Seat Capacity.

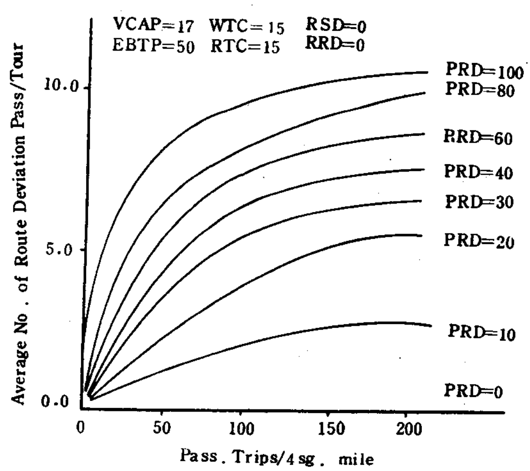


Figure 12. Route Deviation Passenger Productivity vs. Passenger Trip Volume

Figure 11 reveals the effect of the vehicle productivity on the vehicle seat capacity. This figure shows that the vehicle productivities are beld constant even if the vehicle seat capacities are increased when the percentage of the four type's passengers is given as PSP = 40%, PRP = 45%, RSP = 5%, and RRP = 10%.

In other words, the vehicle productivity varies linearly with increasing the size of the vehicle seat capacity. This implies that there are no economic of scale to be gained by designing the larger demand responsive transit to meet the passenger service requested in this service area.

Figure 12 shows that the route deviation passenger productivity per a vehicle tour increases roughly exponentially with increasing the pescentage of the pre-planned route deviation passenger when the passenger trip volume changes between 50 and 200 in the service area

3. Number of Required Vehicles

The number of vehicles required is estimated approximately by dividing the average elapsed time (min.) per tour with the average scheduled head-way which is defined as the time difference between two consecutive vehicle tours dispatched. Figure 13 shows the effect of the number of vehicles required with increasing the size of the service area. This figure indicates that the number of required vehicles increases quadratically with any given percentage of the pre-planned route deviation passengers. It also shows that the number of required vehicles is sensitive according to the % of the PRP. Thus it reveals that the higher percentage of PRP, say more than 60% used, the more vehicle fleet sizes need. This indication will provide some ideas to the DRTS planners and designers. The optimal selection of the PRP will also give not only higher vehicle productivity but also less number of the required vehicles.

Figure 14 shows that the number of required vehicles increases with increasing passenger-trip volumes, and the percentage of the pre-planned route deviation service.

Figure 15 shows that the vehicle seat capacity does not affect too much for the number of the vehicle fleet size. The required vehicle fleet size are almost constant with increasing the seat size. For serving 200 passengers per 4 square miles service area, the vehicle with seat size 15-25 is reasonable in this experiment.

4. Vehicle Headway

The vehicle headway is usually defined as the time interval between two consecutive vehicle's tour starting times, the average vehicle headway within the scheduling period is estimated by dividing the time interval between the first vehicle starting time and the last vehicle starting time with the number of dispatched vehicles.

Figure 16 shows the effect of the size of the vehicle on the vehicle headway. This figure shows that the average vehicle headway time decreases rapidly with increasing the size of the service area. For instance, for a given PRP = 60%, the average vehicle headway time varies from 7.4 to 2.4 minutes between 2-6 the size of the service area. This also reveals that the less PRP used, the longer average vehicle headway scheduled.

Figure 17 reveals the variation of the average vehicle headway for the different level of the passenger trip volumes. This figure also indicates that if the trip volumes increases higher, then the average vehicle headway time generally decreases.

Figure 18 shows that the average scheduled vehicle headway time decreases exponentially through increasing the percentage of the pre-planned route deviation service.

From this experiment, one can also find an idea how be determines the vehicle headway for a given condition.

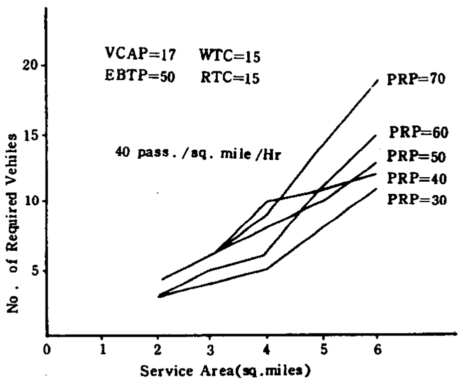


Figure 13. Effect of Area Size on the No. of Required Vehicles

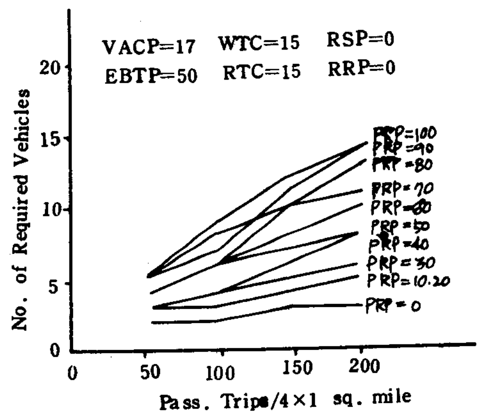


Figure 14. No of Required Vehicles vs. Passenger Trip Volume.

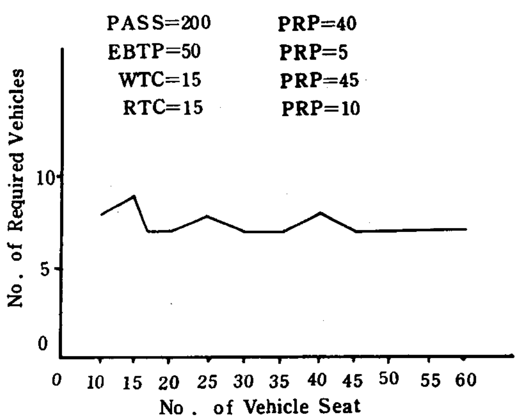


Figure 15. No. of Required Vehicles vs. Vehicle Seat Capacity.

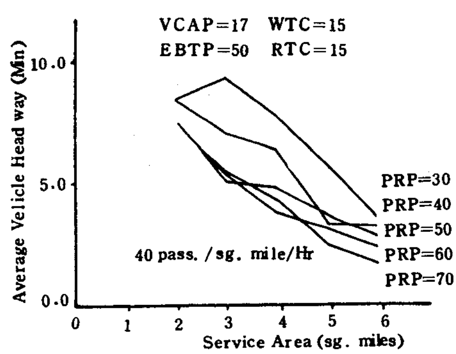


Figure 16. Average Vehicle Headway vs. the size of the Service Area.

As shown in Figure 16-18, it turned out that the scheduled vehicle headway is very sensitive for the size of the service area, passenger trip volumes, and PRP level etc.

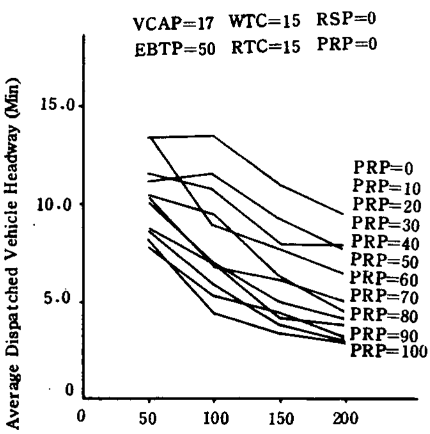


Figure 17. Average Scheduled Vehicle Headway vs. Pass Trip Volumes.

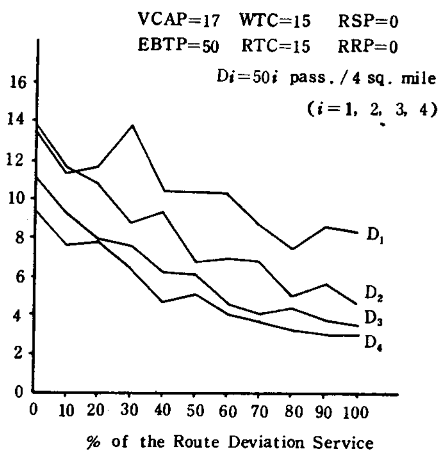


Figure 18. Average Vehicle Headway vs. Percentage of the Pre-Planned Route Deviation Service.

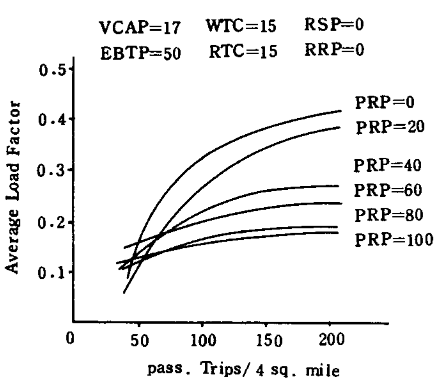


Figure 19. Average Load Factor vs. Passenger Trips.

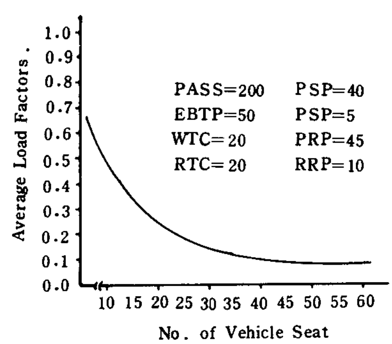


Figure 20. Average Load Factor vs. Size of the Vehicle Seat.

5. Average Load Factor

The average load factor is estimated by dividing the total accommodated passenger's traveled seat miles with the maximum achievable seat miles which are defined as the VCAP&* total scheduled vehicle's traveled distances (Veh-miles). This factor is usually used for seeing how the system utilities used in the simulation period.

Figure 19 shows that the average load factor increases generally with respect to increasing the passenger trips. For the 200 passenger trip volumes, the average load factor the pure station passenger service (i.e. PRP = 0%) is approximately three times of that for the pure route deviation passenger service (i.e. PRP = 100%). This means that the load factor is more sensitive by inserting the more route deviation service over the fixed station service. It also turned out that the load factor shows the decreases for increasing % of the route deviation service in this experiment. Figure 20 shows the interesting effect of the size of the vehicle seat on the average load factor. This figure shows that the average load factor is exponentially decreasing.

From the above discussion, it turned out that the load factor is so sensitive with respect to the rate of route deviation passenger and the vehicle seat seat size. This is because the higher PRD caused the lower vehicle productivity, and the larger vehicle seat size increases the maximum achieable vehicle seat miles.

6. Average Waiting and Riding Time Indices:

Perhaps, good indices of quality of passengers service can be estimated by considering the passenger's waiting time and riding time ratio. The average passenger's waiting time can be measured by dividing the total waiting time of all accommodated passengers through the simulated time period with the total carried passengers times the total number of seperate vehicle tours in scheduling.

Figure 21 shows that the avearage waiting time increased exponentially with respect to increasing percentage of the PRP, particularly when it is greater than 20%, but when it is less than 20%, the figure shows a tendency that the waiting time decreases somehow slowly, but much fastly in case which pure station passenger service has only provided (i.e. PRP = 0%).

Figure 22 shows that the average waiting time for the passengers is so sensitive for the increase of the level of the route deviation service. This implies that more flexible route deviation service are caused more deviation delay while inserting more deviation passengers. From Figures 21-22, passenger's waiting time shows a non linear function of the passenger trips and PRP performed. Since the potential purpose of the sensitivity analysis is aimed at searching the proper schedule for the

the potential purpose of the sensitivity analysis is aimed at searching the proper schedule for the
vehicle allocation with providing the better level of service without breaking any service constraints. The outputs from Figures 21-22 will give us about how to select the percentage of the route deviation service (PRP) for different passenger trip volumes.

The average riding time index is identified by dividing the total travel time spent to accommodate all passengers with the total direct traveled time for them. Figure 23 and 24 show the effects of the passenger trip volume, and the level of the PRP on the riding time idices. The riding time index is increased with respect to the increase of the passenger trips and the percentage of the PRP. In general, the higher volumes of the passenger trips are caused to increase the elapsed riding time because of increasing the travel time by inserting the route deviation service.

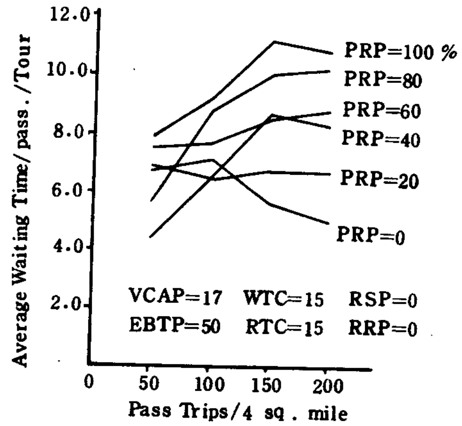


Figure 21. Effect of Pass. Levels on Waiting Time

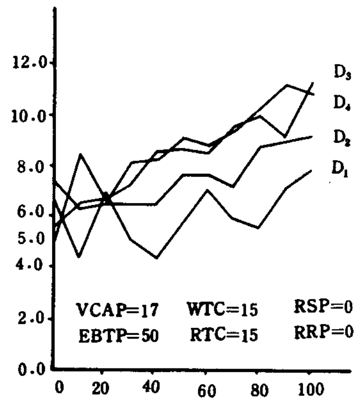


Figure 22. Effect of Levels of Route Deviation Service on the Average Waiting Time.

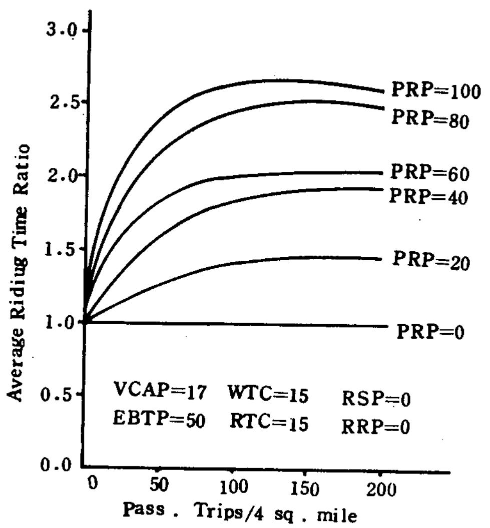


Figure 23. Average Riding Time Ratio vs. Pass. Trip Volume

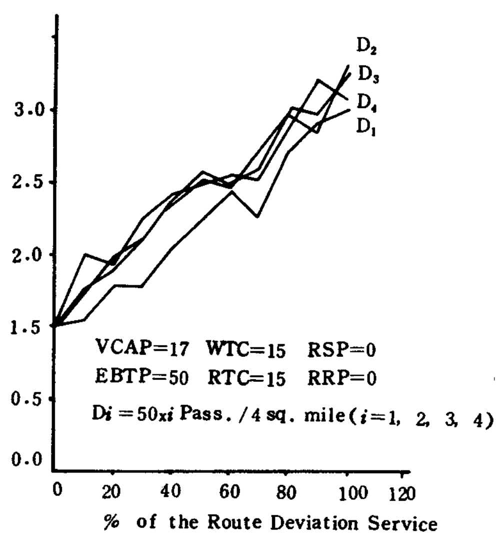


Figure 24. Average Riding Time Ratio vs. % of PRP Service

7. Mean Level of Service and Average Deviation Time per Tour

The mean level of service is defined as the ratio of the total tour time (waiting plus riding time) via the direct traveling time to serve the assigned passengers in the scheduled tour.

Figure 25 shows that the mean level of service is linearly increasing the percentage of the route deviation service. This figure also shows that for a given PRP, the more passengers incurred, the higher mean level of service happened, and the more % of PRP induced the higher mean level of service.

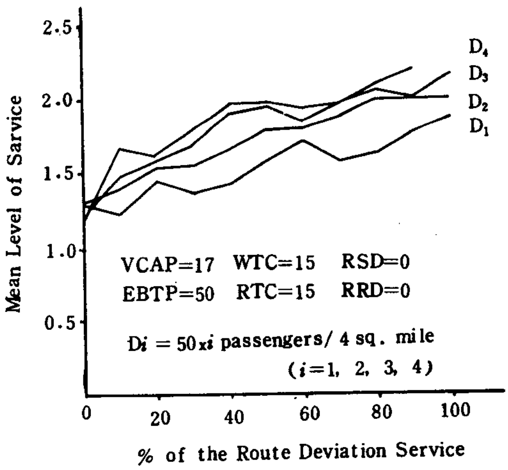


Figure 25. Senstivity of Various Combinations of Route Deviation Service on Mean Level of Service.

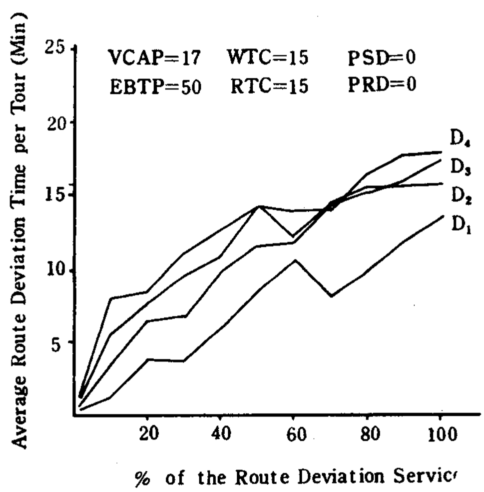


Figure 26. Effect of Various Combinations of Route Deviation Service on the Average Deviation Time per Tour.

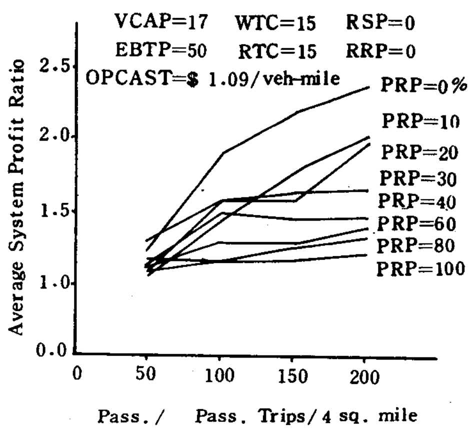


Figure 27. Average System Profit Index vs. Pass. Trip Volumes.

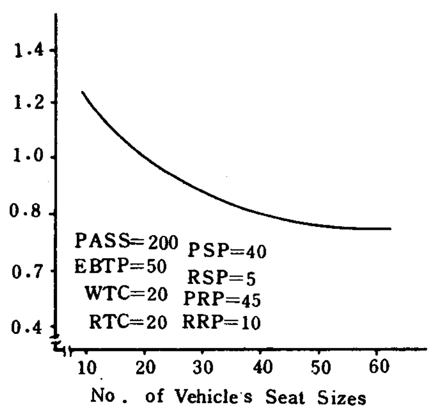


Figure 28. Average System Profit vs. Sizes of the Vehicle Seat.

Figure 26 shows the average deviation time per tour with respect to the various combinations of the percentage of the PRP. This figure shows that the route deviation time per tour is increasing with respect to increasing the % of the PRP. This also shows a tendency to increase with regard to the increase of passenger trip volumes generated in the service area.

8. System Profit Index:

The system profit index per tours is estimated by dividing the total fares collected from all accommodated passengers with the vehicle operating costs.

Figure 27 shows that the system profit index increases with respect to the increase of the passenger trip volumes. This figure also gives that the lower percentage of the route deviation service provides, the higher system profit obtains.

Figure 28 shows the effect of the size of the vehicle seat on the system profit index. This figure also shows that the system profit index decreases exponentially with respect to the increase of the size of the vehicle seat. This is because the vehicle operating cost is strongly dependent of the vehicle seat size.

This situation happens to be more sensitive for the case of increasing the passenger trip volumes.

Figure 29 shows that the average system profit decreases with increasing percentage of the route deviation service.

V. Concluding Remarks

Since the passengers generated in service area are not all required door-to-door service like taxi service, the good attractive demand responsive transportation scheduling systems is probably a mixed systems due to the passenger-patterns and their trip requests. Under this consideration, scheduling algorithm has developed to provide various service of the requests by the different combinations of the passengers generated in the urban service area. Furthermore, the algorithm is primarily concerned with the application of the provisional-tour scheduling technique based upon the pre-planning

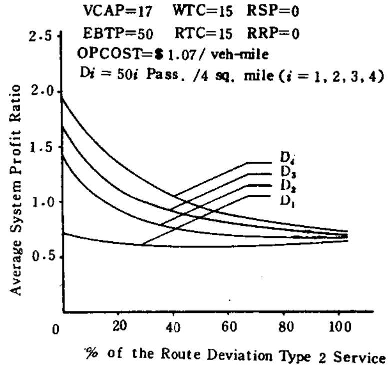


Figure 29. Effect of Various Combinations of Route Deviation Service on the System Profit Ratio.

standards. That is, the scheduling system has the pre-determined route in the given service area, and other characteristics such as the service area, passengers, vehicle, service time, and fare structure. Then the scheduling algorithm is to assign a new passenger into an examined vehicle tour when the ordered passenger is received from the computer reserved bank. This must be done without violating the service time constraints (waiting and riding time) and the link availability constraints by a given vehicle seat capacity for both the new passenger and other passenger already received. Therefore, the algorithm must be decided for which subroute passenger's O-D in terms of overall system performance. Actually this decision is farely complicated by the fact that the system generally governs by the dynamic and random characteristics. However, these complicated problems can be reduced by assuming certain parameters which are governing the scheduling system. So the single vehicle scheduling has under taken in this paper, and pre-determined vehicle route (optimal route) and the passenger priority ordering are incorporated with the scheduling systems as the major factors.

The simulation model is designed under presuming the long lead time and trip repetitiveness to make the pre-planned schedule with handling only certain % of real time unexpected passengers under pre-assumed real time slacks. This simulation model has developed in order to test the scheduling system and a series of simulation experiments have done for the system performances. ***It is turned out that this scheduling algroithm may not be applied to mixed systems with four types of passengers,*** including pre-planning station passenger, pre-planned route deviation passenger. However, it can handle properly for the demand-activated systems and conventional fixed route systems based on the subscription scheduling standard. That is, for the systems with PSP = 100% station passengers it is exactly same as the conventional fixed route service providing various types of service, which for the systems with PRP = 100% route deviation passengers it is similar to the Dial-A-Bus or Dial-A-Ride which provides many-to-many type service, except the *vehicle* must stop at each designated station along the pro-determined route.

Whatever the case may be, the scheduling algorithm can handle efficiently for both pre-planned station passengers and route deviation passengers served along the pre-determined basic route. These results have important implications on the role of proposed scheduling algorithm.

The findings from the simulation experiments are as follows:

(1) the higher passenger density and the higher percentages of route deviation passengers services have provided more frequent service.

(2) the higher percentages (PRP) route deviation passengers used, the more vehicles require, the higher average waiting time, average riding time ratio, average deviation time per tour, average number of route deviation passengers per tour and the average elapsed tour time. In the contrast, the higher percentage of PRP produces the lower average load factor, average scheduled headway, average productivity per tour and the average system profit.

(3) By properly determing various system parameters through a series of simulation experiments, highly efficient scheduling model in terms of overall system performance can be constracted.

(4) The pre-planned schedule, the station passengers affect the average load factors more than the vehicle flect size, while the route deviation passengers affect the vehicle fleet sizes more than the load factor.

(5) The average riding time ratio is more sensitive to the passenger pattern changes than those of the passenger level changes.

(6) By properly choosing the identified station numbers on the pre-determined route, the pre-determined route has only two stations for serving station passengers and also suppose the route deviation service has done between these two stations, then the scheduling system can be designes for providing many-to-one or one-to-many type of service. Particularly when a new rapid transit express bus services or a commuter railload services are provided, the potential many-to-one type of feeder role of demand responsive transportation systems becomes increasingly important. The York Mills Go Dial-A-Bus system was operated as this role of feeder service to the York Mills subway station at the rush hour. While if each identified station is selected as a major focal point to generate more trips such as large commercial and shopping centre, school, hospital and social-recreational activity centre, etc.Located in the service area, then the more efficent scheduling system can be constructed for the sake of many-to-few or few-to-many service which is more likely related to the subscription service.

(7) To achieve a more flexible door-to-door service, the vehicle fleet sizes required would have to be significantly increased. Furthermore, since the vehicle productivities are dependent heavily on passenger requests, and PRP, and service time constraints, by controlling this parameters, the economic seheduling system can be designed.

(8) Programming changes were necessary for the comparison of different selection criteria, but all other variations necessary for the different experiments were made through the input parameters.

(9) At present, it is estimated that for the proposed scheduling systems, vehicle productivities of 9-33 passengers per tour are feasible although they are varying by depending on the passenger pattern changes who request the flexible route deviation service. However, 30%-60% of PRP is cost effective by current implemention.

(10) the scheduling system can also make the shorter average riding time per each passenger by using the minimum path logic technique without visiting the fixed station when no pick up or delivery passengers occurred. By using this optimal routing option, the average elapsed tour time can be significantly saved. But the question is what about the average waiting time per each passenger? The future research may take this.

Futhermore, computer storage requirements are also important when the scheduling systems are constructed as the large-scale systems. Particularly when the larger passenger volumes arrived, most serious problems are computational times and problem size required since computational time grows even faster than exponentially with the number of service area and its relative other factors. Under the current implementation of the PASS, since the maximum storage of passengers is 300. its increasing is not passible to *run the simulation program. This is disadvantage by using this PASS.* So the modification and extension of some sort of subroutines from the PASS should be necessary.

Finally, this reserach was more concerned with the pre-planned schedule and the real time passengers are only served under some probabilistic assumptions because of lack of information for them. Therefore, the future research in this area would seem to be most worth while in connection with simulating real time schedule under the real time passengers in the service area.

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