DISPATCHING POLICY OF VEHICLES FOR PUBLIC TRANSIT WITH OVERLAPPED ROUTES

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abstract: This paper deals with the development of supply model of public transit which is characterized with many overlapped routes. Lack of coordination among services of overlapped routes of public transit may create some problems such as bunching of vehicles and confusion to patronage, so a *good* dispatching strategy for vehicles from terminal is required and expected could release some of the problems. The developed model solves first the problem with decomposition of overlapped routes into several single routes by controlling the frequency of each route. This decomposition is done by developing heuristic algorithm called *Base and Surplus Frequency Procedure* that separates the routes by knowing the fixed and variable arrival of passengers at each stop and controlling the frequency of route service. Secondly the model solves the scheduling or dispatching policy of vehicles with the objective of minimizing total wait or travel time of all passengers. This dispatching policy is made possible with the availability of information on passenger arrival time and his/her origin-destination. The policy is further expected could be the basis for scheduling vehicles of public transit with extensive overlapped routes in practice.

1. INTRODUCTION

Overlapped route in the service of public transit is not uncommon in practice, and it is potential in creating problems both to operators and passengers. For operators overlapped routes may trouble the schedule and create bunching of vehicles at stops, while for passengers it creates confusion among the them. So a good dispatching policy is required to make the service more reliable to the patronage.

Among the operation problems of transit system, the focus of this paper is on the dispatching policy or the optimal scheduling of vehicle departures operated on some routes that share common sections where passenger may take any vehicles to reach his/her destination. There are many terms for determining the dispatching policy, for instance, average wait/travel time per passenger, total travel cost of all passengers, total cost of operating and passengers' cost, etc. This paper, however, discusses the dispatching policy that minimizes total wait/travel time for all passengers for a given number of vehicles or fleet which is not necessarily the fewest number that satisfies total demand.

2. LITERATURE REVIEW

The studies of common bus routes was firstly discussed by Robillard and Chriqui (1975) who formulated the operational assignment to the problem, based on the perceived travel time. On the scheduling problem, the minimum wait time scheduling on a single route for deterministic and time dependent passenger arrival rate was discussed by Newell (1971). He considered the one destination case passengers board a bus at any stops but alight at the last stop only. The case where each bus makes more than one trip was discussed by Salzborn (1972) and Hurdle (1973). The boarding time at each stop was considered in relation to pairing of buses by Chapman and Michel (1978). Jordan and Turnquist (1979) investigated the relationship between the delay at a stop and number of boarding passengers. The effect of the boarding passengers on the scheduling problem was discussed briefly by Friedman (1976).

In this paper, however, an approach to the optimal dispatching policy for public transit vehicles that share common or overlapped sections is discussed. The passenger arrival pattern is analyzed under deterministic case and vehicle travel time is considered to be either constant or function of time. Furthermore, in order to deal with more realistic problems the multiple O-D demand is also adopted.

3. PROBLEM DEFINITION

The problem to be addressed can be defined in the following general terms : given transit service with extensive overlapped routes and passenger arrivals at each stop on the routes, how optimally to dispatch the vehicles from their terminals ?

3.1. Overlapped Routes

The nature of overlapped routes of transit service can be illustrated as shown in Figure 1.

Suppose that several transit services connecting each two terminals on r namely O_r and D_r respectively. These services turn out to be overlapped among them, because they go through some same links (between adjacent stops) and serve the passengers with similar qualities of service. Such transit vehicles are competing to capture patronage going from stop i to stop l are defined as X_{il}

3.2. Time Dependence of Passenger Arrival

In the this dispatching problem, concern is paid to the situation that passenger arrivals are deterministic and time dependent. Moreover it is assumed that these arrivals are not affected by the dispatching policy.

Since passenger arrivals are time dependent, they cannot be considered constant but they follow some arrival rate that can be represented as cumulative passenger arrival by time.

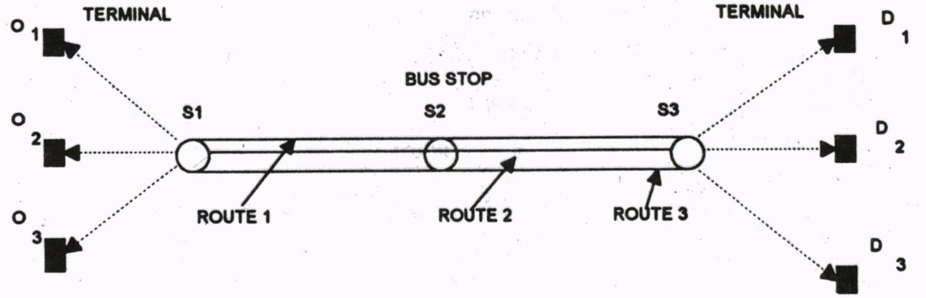


Figure 1. Common Bus Routes

So $F_{ir}(t)$ is defined as cumulative number of passengers arrive at stop i of route r in instant t, as shown in Figure 2.

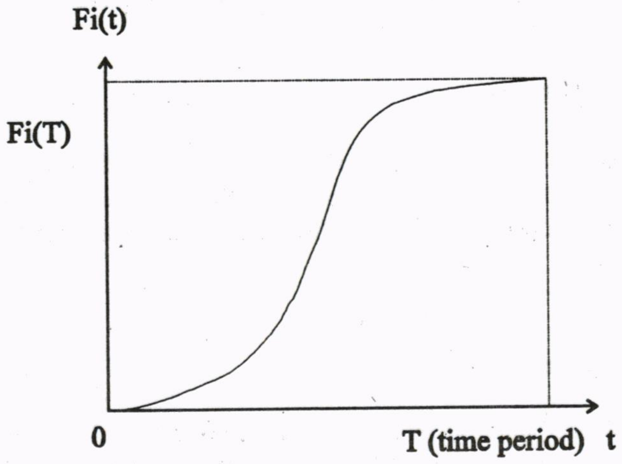


Figure 2. Cumulative Passenger Arrival by Time

3.3. Captive and Variable Arrivals

The model is aimed at solving transit operation with overlapped routes, so there are two types of passenger arrival to be considered, namely captive and variable arrivals that can wait for service at each stop on the overlapped sections.

Captive arrival $CF_{ir}(t)$ is defined as passengers that arrive at a stop i of route r in instant t who can only take vehicle of the route directly to his/her destination without any

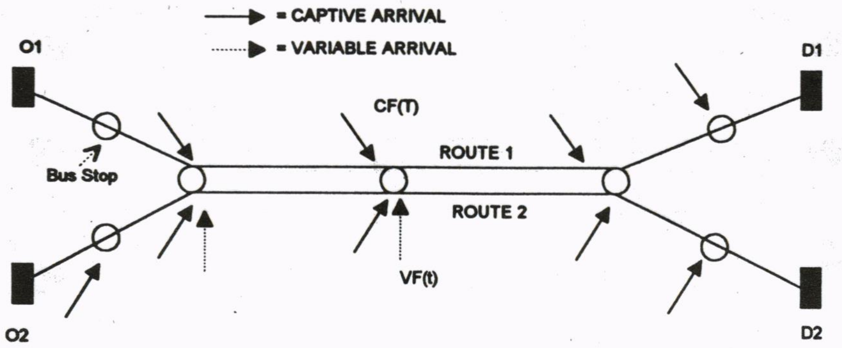


Figure 3. Captive and Variable Arrivals.

transfer. While variable arrival $VF_i(t)$ is defined as the one who can take any vehicle of any route to his/her destination. So when the section deals with some overlapped routes there are captive and variable arrivals, otherwise there is only captive arrival. Furthermore, Figure 3 illustrates the overlapped routes characterized with captive and variable arrivals

4. NATURE OF PROBLEM

In this section, a general solution of scheduling problem of public transit with overlapped routes is developed. The solution developed here is addressed to the component of short range transit planning process, such as to schedule the bus departures during morning or afternoon peak hours.

4.1. General Assumptions

For this general solution some general assumptions are adopted as followings : (1) All vehicles have a same certain capacity; (2) Every passenger will only take the vehicle which will take him/her directly to his/her destination, in other words transferring passenger is not considered; (3) Both captive and variable arrivals are given as a function time.

4.2. O-D Transition Probability

Since passengers take a vehicle from one stop to another, it is necessary to know where each of them goes in order to obtain the optimal dispatch schedule. It is assumed here that the number of passengers on board from stop i to stop l is proportional to the number of passengers boarding at stop i. Since passenger arrival rate at each stop is time dependent, the number of passengers from stop to stop changes over time. The ratio mentioned above is the term called 'O-D Transition Probability' from stop i to stop l, so the O-D transition probability from stop i to stop l of route r is denoted by R_{il}., $R'_{ilr}s$ have the following characteristic,

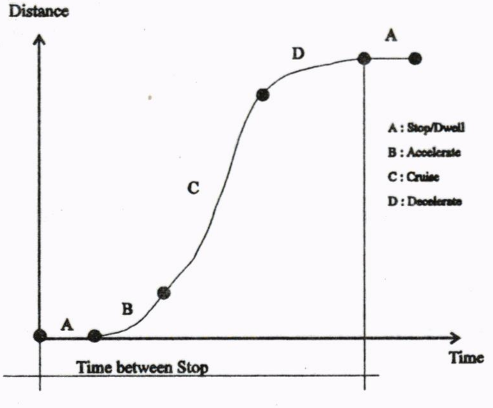
$$\Sigma_{l=i+1}^{D_r} R_{ilr} = 1 \quad \forall \quad i; r \tag{1}$$

Since the $R'_{ilr}s$ are constant over a given time period, the number of passengers carried along a particular link (adjacent stops) can be obtained easily, by multiplying the number of passengers boarding the vehicle at all stops before this link with their $R'_{ilr}s$ and summing up all of them.

4.3. Components of Transit Travel Time

When a transit vehicle travels between two adjacent stops there two major components of time namely moving vehicle time and dwell time. Moving vehicle time is considered as time spent by vehicle to move from one stop to another that includes accelerating, cruising and decelerating time, while dwell time is considered as time spent by vehicle a stop for boarding and alighting of passengers. Figure 4 gives some illustration on transit travel time.

Figure 4. Components of Transit Travel Time



In this model of optimal dispatch, moving vehicle time from i stop to the next stop of route r can be assumed either constant or function of time and denoted by,

$$\Delta t_{ir} = f_{ir}(t) \quad \forall \quad i; r \tag{2}$$

In similar way, the dwell time of the j th vehicle at stop i of route r can be assumed either constant or function of number of boarding or alighting passengers and can be denoted as following,

$$DW_{ijr} = \max(\#BP \times BT; \#AP \times AT) \quad \forall \quad i;j;r \tag{3}$$

where $\#BP, BT, \#AP, AT$ are number of boarding passengers, boarding time/passenger, number of alighting passengers and alighting time/passenger respectively.

4.4. Necessary Conditions for Optimality

The scheduling model developed here is aimed at solving general transit problems. When transit vehicle moves on dedicated infrastructure such as rail system, the travel time between stops can be assumed to be constant. But when transit vehicle moves in the mixed traffic such as bus system then travel time between stops can no longer be assumed to be constant since there is flow dependence between modes and various traffic control.

Minimum Wait Time

The necessary condition for optimal dispatch for dedicated transit vehicle is considered much easier since it can be subject to minimum wait time of all passengers at stops. Figure 5 illustrates the situation where minimum wait time of all passengers can reached by optimal setting of vehicle departures. Suppose a certain number of vehicles (N_r) operated on route r, so the arrival time of the jth vehicle at stop i to pick up all passenger waiting at the stop, $F_{ir}(t_{ijr})$, can produce total wait time of all passengers (W_{ir}) as following,

$$W_{ir} = \Sigma_{j=1}^{N_r} \int_{t_{ij-1,r}}^{t_{ijr}} [F_{ir}(t) - F_{ir}(t_{ij-1,r})]\, dt \quad \forall \quad i;r \tag{4}$$

So the total wait time for all passengers of all routes r with total number of stops of M_r is given by,

$$WT = \Sigma_r \Sigma_{i=1}^{M_r} W_{ir} \tag{5}$$

In Figure 5, W_{ir} is given by the area between the curve and step function created by $F_{ir}(t_{ijr})$ for $t_{ijr} \le t \le t_{ij+1,r}$. Where $t_{i0r} = (t'_{i0r})$ as a time when $F_{ir}(t_{i0r}) = F_{ir}(t'_{i0r}) = 0, t_{iN_r,r} = T$ is some specified period for the last dispatch and $F_{ir}(t_{iN_r,r}) = F_{ir}(T)$ is the total number of passengers who want to board the vehicles at stop i.

In order to minimize W_{ir}, every passenger has to be able to board the first coming vehicle after his/her arrival at stop. This can be proven as follows : Assume that the optimal dispatch schedule has already determined and denoted by t'_{ijr} in which some passengers cannot board the first oncoming vehicle. This kind of schedule is also shown in Figure 5.

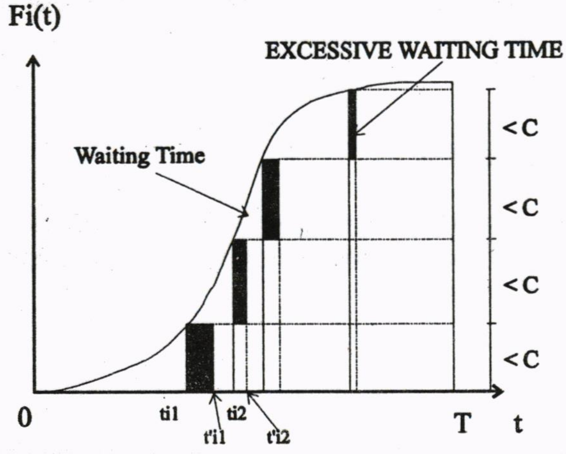


Figure 5. Total Waiting Time of Passengers at Bus Stop

The height of each step is not greater than vehicle capacity (C). In this case, for example, the passengers who arrive at stop during (t_{i2r}, t'_{i2r}) cannot board the first coming vehicle after their arrival. So the number of passengers in the vehicles when they arrive at time t_{ijr}s is not less than the area formed by dispatching vehicles at time t'_{ijr} of the same number of vehicles. That is, for the same number of vehicles and passengers, the wait time decreases if each of them can board the first coming vehicle after their arrival.

Minimum Travel Time

When transit system is dedicated to particular infrastructure (i.e., bus system) then necessary condition for optimality can be subject to some other form such as total travel time which includes wait and in-vehicle time.

In this case total in-vehicle travel time consists of in-moving vehicle and dwell time. In-moving vehicle time for all passengers of all routes r can be denoted by where t_{jr} means the departure time of the j th bus on route r,

$$VM = \Sigma_r \Sigma_{j=1}^{N_r} \Sigma_{i=1}^{M_r} [D_i(t_{jr}) \times \Delta t_i] \tag{6}$$

where $D_i(t_{jr})$ denotes the number of passengers on board of the j th vehicle from stop i to the next stop on route r. While similar to total in-moving vehicle time, the total wait time of all passengers of all routes r can be denoted by,

$$VS = \Sigma_r \Sigma_{j=1}^{N_r} \Sigma_{i=1}^{M_r} [D_{i-1}(t_{jr}) - E_i(t_{jr})] \times DW_{ijr} \tag{7}$$

where $E_i(t_{jr})$ means the number of passengers get off the j th vehicle at stop i on route r.

5. FORMULATION OF PROBLEM

The formulation of dispatching policy problem of general transit vehicles can determined by developing a set of mathematical programming equations which usually consist of objective function and a set of constraints.

5.1. Objective Function

As already mentioned before that the objective function of the problem that satisfies the optimality conditions can be defined either by minimizing total wait time or total travel time. Hence for generality of the problem, the objective function can be given by minimizing total travel time (TT) that comprises also wait time, which is formulated as,

$$Min \quad TT = WT + VM + VS \tag{8}$$

subject to available capacity (C).

5.2. Constraints

Constraints imposed in the problem are generally the availability of total capacity. To derive such constraints it is first necessary to know the number of passengers board the j th vehicle at stop i of route r which is given by,

$$[CF_{ir}(t_{ijr}) - CF_{ir}(t_{ij-1,r})] + \delta_{ir}[VF_{ir}(t_{ijr}) - VF_{ir}(t_{ij-1,r})] \quad \forall \quad i;j;r \tag{9}$$

where t_{ij} is the arrival the j th vehicle at stop i of route r and formulated as,

$$t_{ijr} = t_{jr} + \Sigma_{k=0}^{i-1} \Delta t_k + \Sigma_{k=1}^{i-1} DW_{kjr} \tag{10}$$

and δ_{ir} is 1 when stop i of route r deals with overlapped routes and, 0 otherwise.
The next is to find the number of passengers get off the jth vehicle of route r at stop k, such as,

$$E_k(t_{jr}) = \Sigma_{i=1}^{k-1} R_{ik}\{CF_{ir}(t_{ijr}) - CF_{ir}(t_{ij-1,r}) + \delta_{ir}[VF_{ir}(t_{ijr}) - VF_{ir}(t_{ij-1,r})]$$

$$\forall \quad k;j;r \tag{11}$$

Knowing the number of passengers boarding and alighting at each stop, it is then possible to determine the number of passengers on board of the jth vehicle between two consecutive stops $(i, i+1)$ of route r, which is formulated as,

$$D_i(t_{jr}) = D_{i-1}(t_{jr}) + [CF_{ir}(t_{ijr}) - CF_{ir}(t_{ij} \\ +\delta_{ir}[VF_{ir}(t_{ijr}) - VF_{ir}(t_{ij-1,r})] - E_i(t_{jr}) \quad \forall \quad i;j;r \tag{12}$$

So the constraints of this problem, that the number of passengers on board should be less or equal to capacity, are given by

$$D_i(t_{jr}) \le C \quad \forall \quad i;j;r \tag{13}$$

In the complete form, the formulation of problem can be rewritten as

$$Min \quad TT = WT + VM + VS \tag{14}$$

subject to

$$D_i(t_{jr}) \le C \quad \forall \quad i;j;r \tag{15}$$

$$F_{ir}(t_0) = 0 \quad \forall \quad i;r \tag{16}$$

$$0 < t_{1r} < t_{2r} < \ldots. < t_{N_r} = T \quad \forall \quad r \tag{17}$$

6. PROBLEM SOLUTION

The principal difficulty in solving the optimal dispatch policy for transit vehicles dealing with overlapped routes partially, is that in the overlapped/common routes there are variable arrivals who may take any first oncoming vehicle of any routes to their destination. In spite of this difficulty, the general solution developed here will treat them as separate routes, and the coincidence will be accommodated by appropriately modifying the variable arrivals in the system. The modification of variable arrivals can be done by following 'Base Frequency' and 'Surplus Frequency' procedures explained in the followings.

6.1. Base Frequency Procedure

Base frequency procedure is designed to find lower bound frequency $q_r(0)\ \forall r$, of vehicles operated on route r from the feasible values of q_r in the time period. This value of frequency is necessary to be determined for each route in order to supply demand within the relevant capacity.

To be able to determine the value of q_r, it is required to know the total number of passengers that will be moving on each link (between adjacent stops). The total number of passengers moving from stop i to stop l of route r in the period of T
can be obtained as following,

$$DF_{ilr}(T) = CF_{ilr}(T) + \delta^r_{il} VF_{ilr}(T) \quad \forall \quad il; \in \quad L_r \tag{18}$$

where,

L_r = set of stop pairs on route r
δ^r_{il} = equal to 1 if il deals with overlapped routes, and 0 otherwise
$DF_{ilr}(T)$ = total number of passengers on link il of route r in period T.
$CF_{ilr}(T)$ = total number of passengers of captive arrival on link il of route r in period T.
$VF_{ilr}(T)$ = total number of passengers of variable arrival on link il of route r in period T.

If $VF_{il}(T)$ is total number of passengers of variable arrival moving on link il without regarding the route r, it can be divided between routes of competing section in proportion to their frequency shares as $VF_{ilr}(T)$. In that case the equation (18) can be rewritten as,

$$DF_{ilr}(T) = CF_{ilr}(T) + \delta^r_{il} \frac{q_r}{\sum_k q_k} VF_{il}(T) \quad \forall; il; k \in X_i \tag{19}$$

where,

q_k = vehicle frequency operated on route k
X_{il} = a set of routes between stop i and l that coincide

Base frequency procedure - to find the lower bound $q_r(0)$ for each of q_r, to serve this purpose the following heuristic algorithm is developed to generate the lower bound frequency in the specified time period and satisfy that no excess capacity is violated on the peak load on each link on the route.

Base Frequency Algorithm

Step 1. For given routes, determine $CF_{ilr}(T)$, $VF_{il}(T)$ and X_i for every stop pair il and route r.
Step 2. Using only the captive passenger flow determine the frequency from,

$$C \times q_r(0) = \max_{il}[CF_{ilr}(T)] \quad \forall \quad r; il \in L_r \tag{20}$$

where,

C = vehicle capacity

L_r = set of links on route r

Set $n = 0$.

Step 3. Compute $DF_{il_r}(T)$, using equation (19), where $q_r = q_r(n)$.

Step 4. Find the peak load link passenger flow on each route. If the peak load link of each route is the same as that identified in the previous iteration, STOP and set $q_r(0) = q_r(n)$. Otherwise, set $n = n + 1$.

Step 5. And redefine the $q_r(n)$ as the solution to the following equation,

$$C \times q_r(n) = \max_{il}[DF_{il_r}(T)] \quad \forall \quad r; il \in L_r \tag{21}$$

then go to Step 3.

It is clear that there are a finite number of different combinations of peak links (one for each route) that can be found in Step 3 of the algorithm. Therefore, it is expected that the algorithm will converge within a finite number of iterations.

6.2. Surplus Frequency Procedure

In the base frequency procedure lower bound feasible frequency on each route can be obtained. This value implies that the supply to demand is given at, or close to, capacity. But in order to obtain the minimum wait/travel time and to improve service quality as well, the 'Surplus Frequency' procedure provides feasible value of q_r such as ,

$$q_r \geq q_r(0) \quad \forall r \tag{22}$$

Therefore by using the feasible value of q_r provided by surplus frequency procedure, the optimal number of vehicles running on each route can be determined which is not necessarily the fewest as to minimize wait/travel time without violating the capacity constraint and to improve service reliability.

By following the base and surplus frequency procedures, the problem of finding optimal dispatch policy for transit vehicles dealing with overlapped routes can be treated as separate routes. The variables of separate routes are also modified by the procedures and solved in the following steps;

Step 1. Find value of $q_r(0) \quad \forall r$ using the base frequency procedure.

Step 2. Find feasible value of $q_r \forall r$, such as $q_r \geq q_r(0)$, using surplus frequency procedure.

Step 3. Modify the variable arrivals for each route such as,

$$VF_{ir}(T) = \frac{q_r}{\sum_k q_k} VF_i(T) \quad \forall \quad i; r; k \in X_i \tag{23}$$

where, X_i is a set of overlapping routes passing through stop i.

Step 4. Minimize wait/travel time for all passengers of captive and variable arrivals, subject to capacity constraint, as single route.

6.3. Dynamic Programming for Minimizing Wait/Travel Time

Having all routes in the system as separate routes, it is then remained to solve the objective. Objective function and its constraints shown in equations (14) - (17) are non-linear in general and can be easily solved by using dynamic programming.

In this optimization problem headway between the $(j-1)$th and the jth vehicle from starting point O_r can be chosen as decision variable, $s_j \; \forall j$, where s denotes the time interval between the beginning of time period of interest and the first dispatch of transit vehicle. The stage corresponds to each dispatched vehicle and state variable, $Q_{jr} \forall j$, is the time interval between the beginning of the period of interest and the jth dispatch. Furthermore, the recursive relationship of this problem in the dynamic programming solution is given by,

$$r_j(Q_{jr}) = \min_{s_j} [r_{j-1}(Q_{j-1,r}) + f_j(s_j)] \tag{24}$$

where $r_j(Q_{jr})$ is the minimum wait/travel time for j vehicles from the first, and $f_j(s_j)$ is the wait/travel time for the jth vehicle. And the state of dynamics is given by,

$$Q_{jr} = Q_{j-1,r} + s_j \tag{25}$$

The model and its solution algorithms have been developed and summarized in a single package program called ***Sched***, written in FORTRAN language. ***Sched*** comprises of some modules covering the base frequency and surplus frequency procedures and the dynamic programming solution for the problem's objective. In the following section, an example is given in order to provide illustration how the developed model and package program work to solve the problem of optimal dispatch policy for transit vehicles.

7. AN EXAMPLE

In the following discussion, to see how well the algorithm incorporated in ***Sched*** works, a simulation on dispatching of transit vehicles with overlapped routes is given . Figure 6

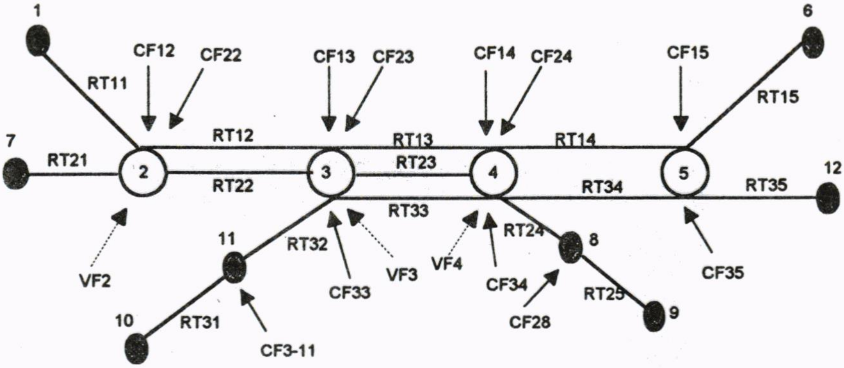


Figure 6. Transit Network Example

shows three routes having four common stops. Each of these four stops have captive and variable arrivals.

Prior to running the software, the program requires data input such as boarding and alighting time, O-D transition probability, vehicle capacity, number of routes, number of stops and service time block.

In this example, data which is input into the program is as follows ;

a. Service time block : 60 minutes
b. Average passenger boarding time (α) : 0.1 min/pax
c. Average passenger alighting time (b) : 0.08 min/pax
d. Vehicle capacity : Route 1 = 40 pax ; Route 2 = 40 pax ; Route 3 = 40 pax
e. Passenger arrival function :

$CF12(t) = 0.41667 + 0.01667\,t + 0.00757\,t^2$
$CF13(t) = 0.5 + 0.03333\,t + 0.00511\,t^2$
$CF14(t) = 0.46944 + 0.01278\,t + 0.00278\,t^2$
$CF15(t) = 0.67222 + 0.03222\,t + 0.00556\,t^2$
$CF22(t) = 0.7 + 0.02333\,t + 0.00394\,t^2$
$CF23(t) = 0.13333 + 0.02667\,t + 0.00633\,t^2$
$CF24(t) = 0.2 + 0.02667\,t + 0.00556\,t^2$
$CF28(t) = 0.5 + 0.04333\,t + 0.00638\,t^2$
$CF311(t) = 0.55556 + 0.02222\,t + 0.00222\,t^2$
$CF33(t) = 0.12333 + 0.03333\,t + 0.00438\,t^2$
$CF34(t) = 0.22222 + 0.02222\,t + 0.0556\,t^2$
$CF35(t) = 0.51111 + 0.05778\,t + 0.00811\,t^2$

$VF2(t) = 0.27778 + 0.01111\,t + 0.00311\,t^2$
$VF3(t) = 0.25 + 0.01667\,t + 0.00556\,t^2$
$VF4(t) = 0.28611 + 0.08944\,t + 0.00594\,t^2$

$RT11(t) = 2 + 0.04167\,t$
$RT12(t) = 7 + 0.08333\,t$
$RT13(t) = 5 + 0.06667\,t$
$RT14(t) = 4 + 0.05\,t$
$RT15(t) = 3 + 0.083333\,t$
$RT21(t) = 3 + 0.06667\,t$
$RT22(t) = 7 + 0.08333\,t$
$RT23(t) = 4 + 0.06667\,t$
$RT24(t) = 3 + 0.04167\,t$
$RT25(t) = 3 + 0.06667\,t$
$RT31(t) = 5 + 0.05\,t$
$RT32(t) = 5 + 0.08333\,t$
$RT33(t) = 5 + 0.06667\,t$
$RT34(t) = 4 + 0.05\,t$
$RT35(t) = 2 + 0.04167\,t$

g. O-D Transition Probability ;

OD-CF Route 1 :

	1	2	3	4	5	6
1						
2						1.0
3						1.0
4						1.0
5						1.0

OD-CF Route 2 :

	7	2	3	4	8	9
7						
2					0.4	0.6
3					0.3	0.7
4					0.25	0.75
8						1.0

OD-CF Route 3 :

	10	11	2	4	5	12
10						
11			0.1	0.25	0.3	0.35
2						1.0
4						1.0
5						1.0

OD-VF :

	1	2	3	4	5	6	7	8	9	10	11	12
1												
2			0.2	0.35	0.45							
3				0.4	0.6							
4					1.0							
5												
6												
7												
8												
9												
10												
11												

The result of the model for this example is shown in Table 1 and its comparison with a constant departure time (non-model) is shown in Table 2.

Route	Vehicle	# of Stops				
1		1	2	3	4	5
	1	22	25.6	35.48	43.41	50.04
	2	32	35.94	46.29	54.19	60.51
	3	56	62.56	75.38	84.63	91.96
2		7	2	3	4	8
	1	16	20.43	29.58	36.47	41.39
	2	30	35.5	46.06	53.99	59.46
	3	54	61.98	74.85	83.57	89.49
3		10	11	3	4	5
	1	20	26.26	33.7	41.57	46.57
	2	54	62.42	73.48	83.78	91.72

Table 1. Vehicle Departure Time of Example Problems

# of Bus	# of Route					
	1		2		3	
	Model	Non Model	Model	Non Model	Model	Non Model
1	22	20	16	20	20	30
2	32	30	30	40	54	60
3	56	60	54	60		
Total Wait Time	2,300.55	2,587.16	2,633.46	3,332.8	3,094.72	3,529.3
Total Travel Time	2,011.32	2,015.3	1,730.97	1,766.3	1,094.69	1,124.26
Total Time	4,311.88	4,602.46	240,271.9	5,098.83	4,189.06	4,653.53
Overcrwd.		1		27		23

Table 2. Comparison of Results for Model and Non-Model

8. CONCLUSIONS

The paper deals with the development of dispatching policy of transit vehicles that deal with overlapped routes. The model treat the routes as separate ones, and this is made possible by following the *base* and *surplus* frequency procedures. Having the routes separate, it is then remained to solve the objective of problem in which in this case a *dynamic programming* method is proposed as tool for the solution. Dynamic programming is chosen here, since the objective function and its constraints are non-linear in nature which is difficult to solve using other approaches.

The developed model and proposed solutions covering base and surplus frequency procedures and dynamic programming are summarized in the package program called *Sched* which is written in FORTRAN language. The package is capable of solving problems of small to medium scales, and expected not to have any serious difficulty for large scale problems when accommodated with enough memory and suitable hardware.

Furthermore, the model is expected to be useful tool for analyzing any design variables for making decision in optimal dispatch policy for transit vehicles dealing with overlapped routes. These design variables include parameters of boarding and alighting passengers, cruising time of vehicle, passenger arrivals and many others.

The assumption of all passenger arrivals are deterministic is somewhat unrealistic in practice, so the development of model that consider stochastic behaviour is preferable. The discussion and deevelopment of such model has, however, been developed by the first author and interested reader may refer to Sutanto (1989).

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