ECONOMIC IMPROVEMENT OF PUBLIC TRANSPORT BY DEMAND-ORIENTED ROUTE OPTIMIZATION

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ABSTRACT

Existing public transport networks do often not correspond to the actual land use pattern. This leads to shortage as well as to surplus in public transport supply. Both produce negative economic consequences.

The algorithm developed in the following paper tries to discover and correct the divergencies of land use and network configurations using demand-oriented route optimization, and thus represents a contribution to the economic improvement of public transport.

1. INTRODUCTION

It is commonplace that running public transportation systems means in most cases loosing money. This might be the reason for the fact that economic principles often do not have the weight they should have in public transportation planning. At least in private enterprises it is well known that the most economic supply is the one regulated by demand. Why not transfer this principle to the field of public transport planning! Although the aim of such endeavour cannot be making profit by public transportation, the chance of possibly reducing the losses should be worthwhile enough.

Absolutely new transport technologies are unfinanciable at present, so that investigations focus on the improvement of todays conventional public transport systems. Here unexhausted possibilities of improvement seem to be at the basis of the transportation supply: the existing route configurations. Their change according to the structure of spatial transportation demand may establish more attractive and more effective public transport routes without increasing the operating expenses.

References to this particular subject are quite scarce. Most of them are not explicitly demand-oriented, referring to complete network design more than to individual route planning. Thus Holroyd [3] calculates the optimum size of a square grid side to minimize total travel time, while Byrne [1] gives a solution for the radial case. Byrne and Vuchic [2] present a method for deriving the line positions which minimize total system and user costs. Rapp et al. [5] give an interactive graphic method for transit route optimization. Methods of operations research are used by Rosello [6], van Oudheusden [4] and Sonntag [7].

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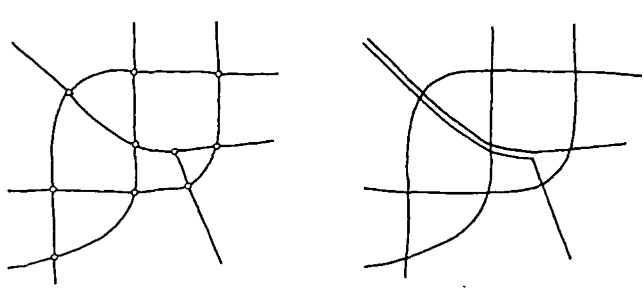
2. PROBLEM DEFINITION AND OBJECTIVES

A general instrument to make public transport more attractive are speed-up measures reducing the travel times on the routes. That means often make the second step before the first one, as the travel time on the route is reduced indeed, but the alinement of the route itself within the whole transportation system remains unproved. This is opposite to the fact that changing the route configuration is often more effective and above all less expensive than comprehensive speed-up measures will be. The reason for keeping the routes nevertheless unchanged might be that there is hard lack of a practicable procedure which enables the planner to really construct public transport routes and not only find the relatively best ones out of a number of previously fixed network variants. The gap thus described shall be closed by the algorithm outlined in this paper.

The objective of the algorithm is the direct transformstion of an existing travel demand structure into an optimal configuration of public transport routes. Optimal means here: serve a maximal number of passengers by direct connections on routes with minimal travel times, and that without overdrawing the operating means being at disposal.

3. METHOD OF SOLUTION

The design of routes is one of the most essential steps within the transportation planning process. While the individual transport rider has the chance of "free" route choice, the chance of public transport planning is the supply of optimal collective routes. As their computation is quite comlex, simulation in model is inevitable. Nucleus of the model is the development of a network of optimal routes out of a given network of links. Both types of network are shown in figure 1.



Network of links Network of routes

Figure 1: Types of network

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3.1 MODEL INPUTS

Model input on the side of transportation demand is the passenger trip matrix $\{F_{ij}\}$, with its field (i,j) denoting the number of riders in public transport from zone i to zone j. The matrix might be obtained from a passenger survey or as result of a trip table computation based on the land use data of the survey area.

Model input on the side of transportation supply is the given network of links (see figure 1). Each link is weighted by its travel time. Components of travel time in public transport apply to the time required for

- walking from centroid of zone i to the vehicle stop
- waiting until the vehicle arrives
- interchange. Both, times for waiting and interchange are dependent on the vehicle frequency
- transport on bord of the vehicle
- walking from vehicle stop to the centroid of zone j.

While for reasons of simplification the centroids of the zones are understood to be congruent with the nodes of the link network, and while vehicle frequencies will be computed only after later iteration steps, travel time at the beginning is reduced to the time for transport on bord of the vehicle.

Thus the link network consists of nodes $\{p\}$ = p1, p2... etc and of links $\{s\}$ = s1, s2... etc., each link weighted by its travel time t_{xy}, with $x,y \in \{p\}$ and (as simplification:) $\{p\} \in \{i,j\}$.

3.2 THE ALGORITHM

To transfer the two parts of model input, demand structure and network of links, into a network of optimal routes $\{R\}$, each single route R is subject to the following objective functions:

(1) $\Sigma\, t_{ijR} \overset{!}{=} \min$ (t = travel time on route R)

(2) $\Sigma\, D_{ijR} \overset{!}{=} \max$ (D = direct riders on Route R)

(3) $\Sigma\, F_{ijR} \overset{!}{=} \max$ (F = number of trips on route R)

As the three components together are not without contradictions, they will be relativated. This means for function (1), that the actual minimum of travel time is not the shortest travel time, but the product of the absolutely shortest travel time and a detour factor f to limit the actual admissible travel time.

The detour factor f itself has a central significance within the philosophy of the algorithm, because f is on the part of the user decisive (among others) for the level of service, and on the part of the operator decisive (again among others) for the efficiency of the route, as f determines the grade of trip bundling.

The same holds also true in case of the functions (2) and (3): the number of trips respectively passengers being direct riders on one route will (again) be dependent on the detour factor f. The optimal value of f will be part of a special investigation not included in this paper.

The particular compilation steps of the algorithm are depicted in the flow chart of figure 2. After data input the detour factor f is defined being relevant for one complete network compilation. During the compilation process it is differentiated between a complete public transport route R_n (with n = 1,2 ...) and part of it, which is called subroute r_{ay} leading from node a to node y. Node a is the starting point of a transit route with $a \in \{q\}$, while $\{q\}$ is the set of potential starting points, so that $\{q\} \in \{p\}$. The set of $\{q\}$ has to be introduced by hand of the planner and will normally be dependent on existing facts such as bus terminals, main stations etc.

The algorithm takes as starting point a out of $\{q\}$ the one node that delivers the highest sum of origin and/or destination trips. Next we define S_{aj} to be the patronage of direct riders on the route from node a to node j respectively vice-versa. Initially we denote all $\{S_{aj}\} = 0$.

To find all nodes $\{y\}$ adjacent to a, we equate a = x and determine the first node y adjacent to node x. Thus a first subroute r_{ay} is formed, and we have to check three conditions:

(A) No loops within r_{ay}

(B) $S_{ay} > S_{aj}$

(C) All $\{t_{iy}\}$ admissible | for all $\{i\} \in r_{ay}$

Condition (A) is a basic assumption for all kind of route planning. Condition (B) guarantees, that the route just compiled will transport more direct riders than the hitherto solution has done. Condition (C) prevents longer than admissible divergences from the actual shortest route.

In case of all three conditions being satisfied, the previous value of S_{aj} is replaced by S_{ay}, and y = x is stored for one of the next steps. That will be after having processed all nodes $\{y\}$ adjacent to (initially) x = a.

The calculation continues until all nodes x are processed. Then S_{ajmax} defines the final point j of the route R_n with the maximum patronage of direct riders, each of them needing no more travel time than actually is admissible.

After erasing the processed values of F_{ij} in the trip table, the procedure is repeated. The alinement of the routes, defined by the sequence of their nodes, can be determined by the notation of the actual preceding nodes.

Next step is measuring of the vehicle operations according to the passenger volumes on the routes. The result will be the

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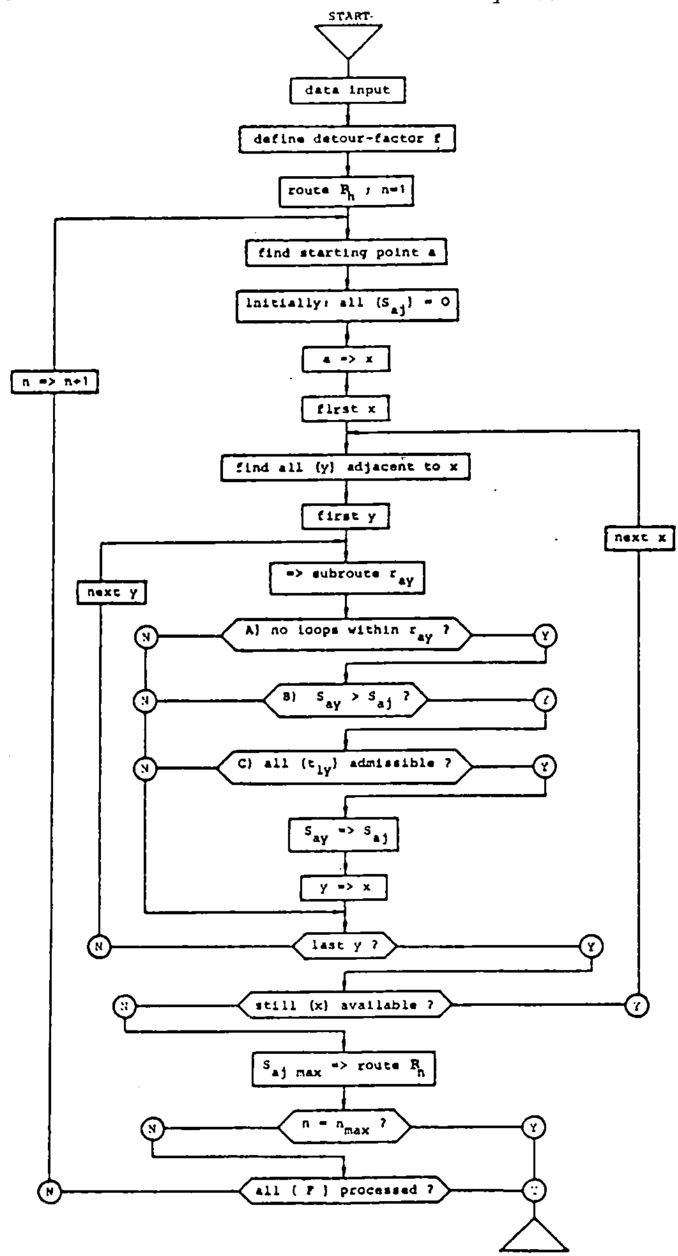

Figure 2: Flow Chart of the Algorithm

vehicle frequency and by that: the odd number of vehicles to be held in readiness. Thus the compilation of routes is ended, when the number of vehicles being available is exhausted. That will be with route-number $n = n_{max}$.

In addition to the compilation steps of the flow chart further iteration steps are necessary to meet the real values of the travel time with its components mentionned above. Only when the changes of vehicle frequency with their influences on travel time do not lead to changes of the alinement of the routes, the compilation process may be terminated.

3.3 MODEL OUTPUTS

Result of the compilation process is a set of routes which together form the public transport network. The final assignement of all passenger trips to this network will lead to route respectively link volumes which are additionally augmented by interchangers. Of course this augmentation requires another revision of the vehicle frequencies.

The results represented in this paper restrict on the first iteration step pointing out the following characteristics per route:

- alinement of the route R_n determined by the sequence of nodes between node i =a and node j
- patronage of direct ridership
- length of the route
- expenditure of time (weighted)
- average travel time
- effective detour factor (weighted)
- percentage of direct ridership of the route to total ridership of the network.

Assuming for instance average figures for travel speed, occupancy rate and daily performance per bus, the odd number of the requisite vehicles may be calculated and be checked with the available means of the operator.

4. APPLICATION AND PRACTICAL EXPERIENCE

The algorithm has been programmed in FØRTRAN IV and was applied to the idealized public transport network of a large town in West Germany.

The basic link network of the town is shown in figure 3. The numbers at the links indicate the travel times in [sec]. Travel times of 1 sec are only computational values.

The corresponding trip demand matrix of the town based on a passenger survey has proved to bulky to be depicted here. To give an idea of the existing situation, the present link volumes are shown in figure 4.

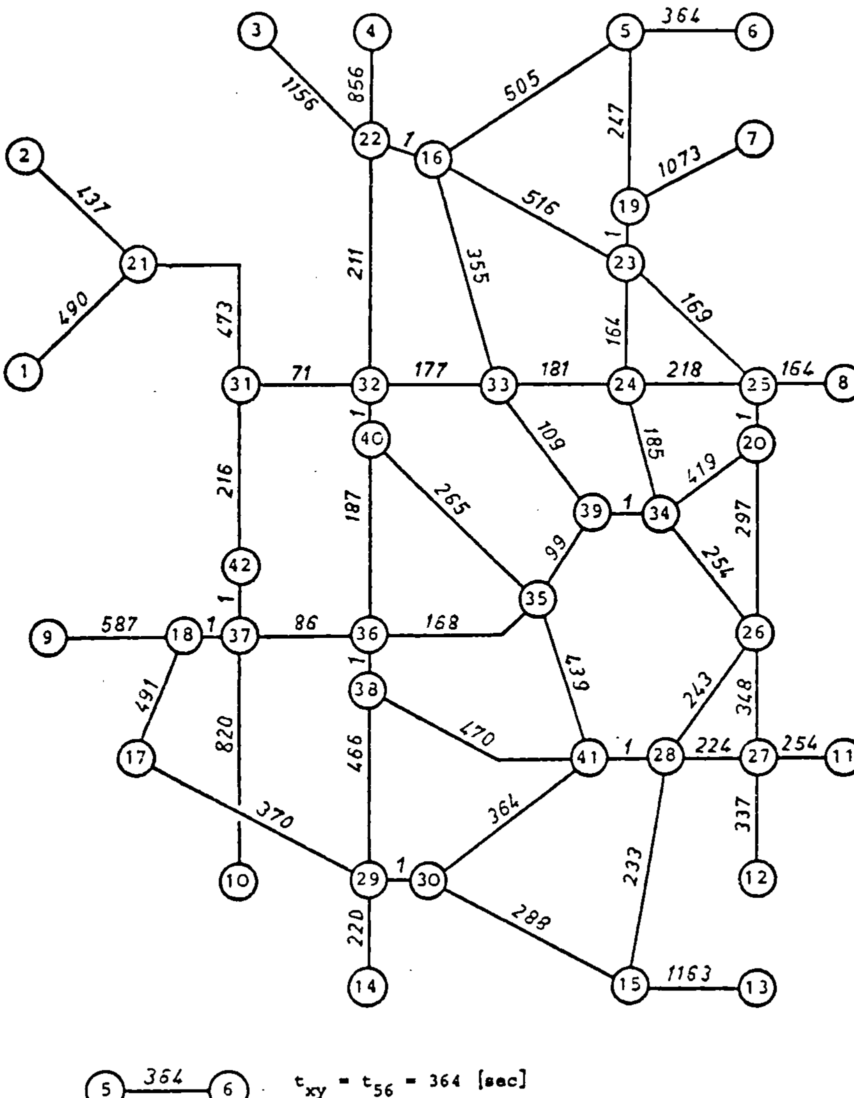

Figure 3: PT-network (idealized) of a large town in West Germany

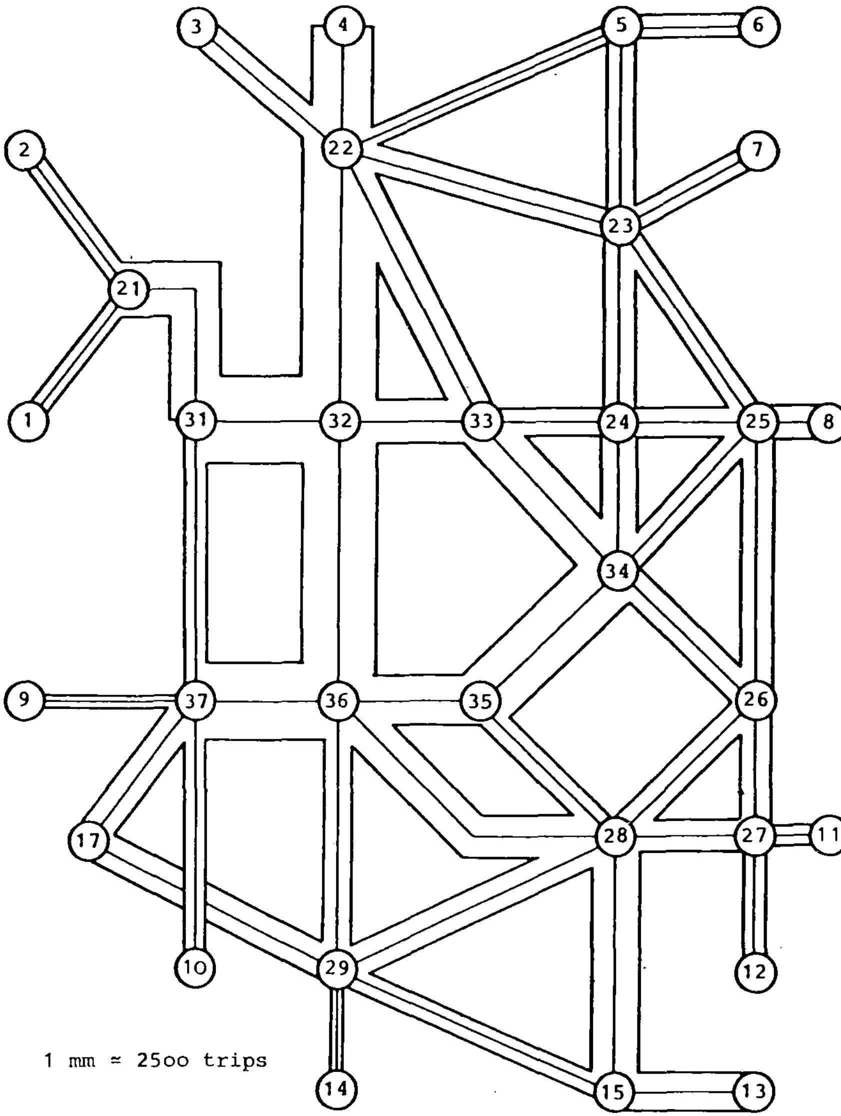

Figure 4: Existing Link Volumes of the Idealized PT-Network

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The application of the algorithm has lead to the computational results reproduced in figure 5. They refer in the lower half of the table to the characteristics of n = 10 routes, mentionning supplementary the provisional results for n = 5 routes in the upper half of the table, each referring to 3 different detour factors.

Although the values of figure 5 depict only a small part of the total result, they are quite expressive. They make evident, that the percentage of direct to total ridership in a PT-network is indeed a function of the detour factor. Although the factor itself will in some range be influenced by political and/or economic decisions, also input data such as actual land use configuration and network structure seem to be relevant. Thus in the case under discussion, f = 1,5 produces the relatively best values. The route network with f = 1,5 and n = 10 routes is depicted in figure 6.

To evaluate the operational realizability of the plan, a rough estimation of the requisite daily passenger space supply is possible. Assuming for instance the followings:

- commercial speed 20 km/h
- occupancy rate 70 %
- daily km/vehicle 250 km

we get in case of n = 10 routes and f = 1,5 an odd number of

$$\frac{43\ 177 \cdot 2o}{o,7o \cdot o,6o \cdot 25o} = 84oo \text{ passenger spaces}$$

Assuming 75 passengers as capacity/vehicle, there would be a requisite number of 112 vehicles.

Although the operational part of the computations restricts on only rough estimations, it can be stated that the application of the algorithm has brought out two main results:

a) The portion of direct ridership could be raised by 5% from 55% to 6o%

b) The daily passenger space supply could be diminished from approximately 1o5oo to 84oo passenger spaces.

Taking both results together, a plus in the level of service for the user could be attained by a minus of the operational expenses for the operator. This should at any rate be called an economic improvement.

5. CONCLUSIONS

(see page 12)

Fig. 5: Computational results of the algorithm's application to the PT-network of a large town in West Germany

no. of routes	characteristics of routes / detour factors	no. of direct riders	route length	expenditure of travel time	average travel time	effective detour factor	percentage of direct to total ridership
		/	[km]	[pass.h]	[min/p.]	/	[%]
5	f = 1,0	64 088	72,50	19 662	18,41	1,000	27,95
	f = 1,5	92 482	83,15	28 887	18,74	1,053	40,33
	f = 2,0	115 920	86,05	41 891	21,68	1,131	50,55
10	f = 1,0	94 514	136,29	29 211	18,54	1,000	41,21
	f = 1,5	137 802	148,71	43 177	18,78	1,043	60,09
	f = 2,0	149 042	167,41	53 757	21,64	1,125	64,99

Note: The registered figures denote either totals (column 1-3) or average values (column 4-6). The figures of column 3-5 refer only to direct riders.

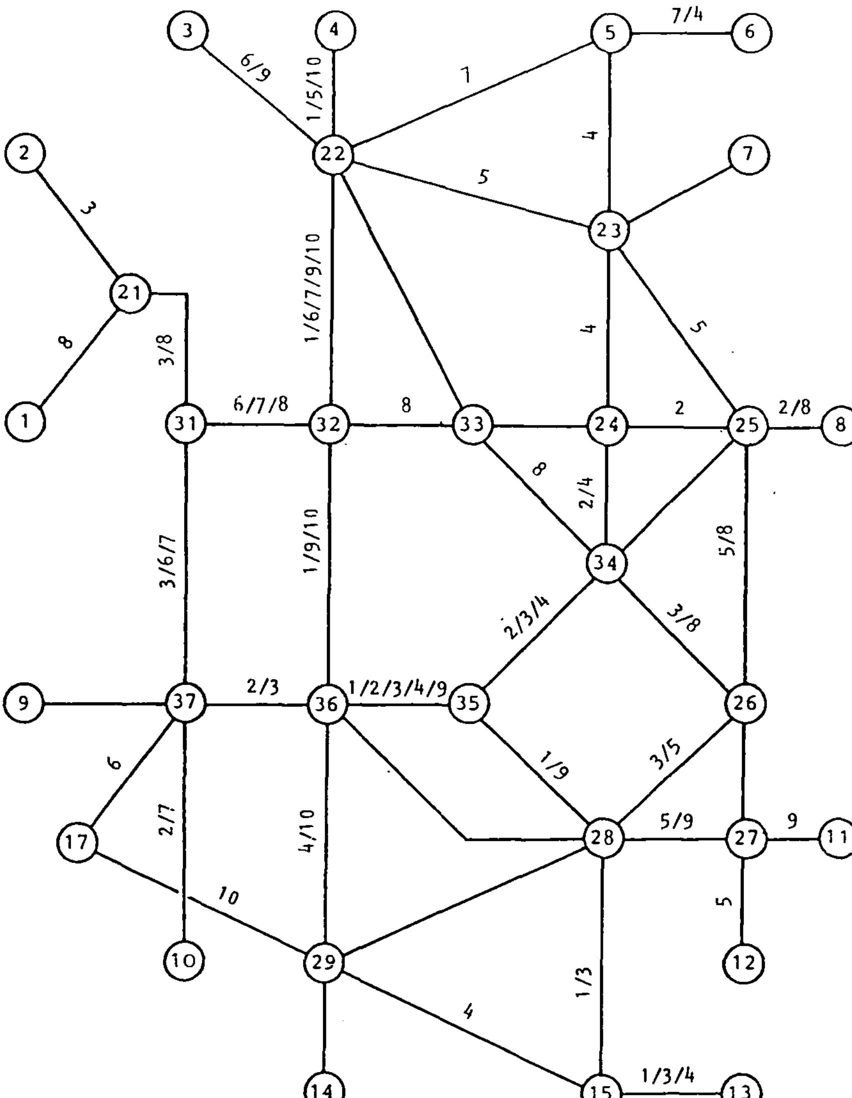

Figure 6: Route Network with Route Numbers
for n = 1o Routes and f = 1,5

5. CONCLUSIONS

The demonstrated algorithm seems to be superior to the hitherto prevalent methods of route planning. The mathematical formulation and combination of the three criteria

- minimal travel time
- maximal route directness and
- maximal patronage (on the route)

results in advantages for both, user and operator.

Possibilities of interactive intervention during the compilation process are given for instance

- to select special final points of the routes
- to equalize peak volumes in route patronage
- to reduce the detour factor according to growing volumes on the routes.

Fields for further practical application of the algorithm might be:

- revision and correction of existing PT-networks according to changes in the land use and/or link network pattern
- design of PT-networks in the course of establishing transport and fare pool systems
- construction of additional single routes within an existing public transport network
- correction of existing PT-networks with regard to possible road improvements, new bus lanes etc.
- determination of improvement priorities for network elements
- supporting design and operation of demand-responsive PT-systems.

Finally it seems that it is well possible to make passengers individual interest part of mass transit planning. As improved public tranport routes will increase public transportation demand, the economic effect of the algorithm is additionally intensified.

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