PUBLIC TRANSPORT ROUTE OPTIMISATION METHODOLOGY IN SOUTH AFRICA

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ABSTRACT:

During the last few decades public transport demand patterns in South African metropolitan areas have changed considerably due to market forces such as urban decentralisation and informal settlement on the urban fringes. Public transport services did not respond to these changing demand patterns in an optimal way and great potential exists to optimise the route network of bus and mini-bus taxi services.

In view of changing demand patterns and the need for metropolitan authorities to develop an integrated multi-modal public transport plan in terms of the new National Land Transport Bill, three authorities applied a public transport route optimisation model to assist in the optimisation of bus and taxi route networks. The DHV Route Optimisation model, developed in the Netherlands, was transferred to South Africa for these studies. The model determines the most optimal set of road based routes, subject to resource constraints, by minimising the total travel time and number of transfers between routes.

The paper defines the need for route optimisation in South Africa, describes the DHV model and adjustments made to suit South African conditions, and presents the main results of the route optimisation studies conducted in the Greater Pretoria, Khayalami and Port Elizabeth metropolitan areas. Finally, recommendations are made regarding the route optimisation methodology to be adopted in South Africa in view of lessons learned from the three applications.

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1. INTRODUCTION

All spheres of government in South Africa are currently in the process of restructuring public transport. The new Land Transport Bill (13 March 1998) requires transport authorities to develop an operational public transport plan as part of an Integrated Transport Plan. A key component of the public transport plan is the development of an integrated public transport route network including all appropriate modes of transport which will serve current and expected future demand patterns in an optimal way.

In anticipation of its role as a transport authority, the Greater Pretoria Metropolitan Council (GPMC), expressed the need for a planning tool which would assist them to optimise the public transport route network of the GPMC area. The GPMC subsequently appointed Stewart Scott (Pty) Ltd to identify such a planning tool and to test and apply it in the Greater Pretoria area.

With the assistance of its international partner, DHV Consulting Engineers, Stewart Scott reviewed a wide range of transport models and concluded that the DHV route optimisation model was the best tool meeting the requirements of the GPMC. This model was first pilot tested and subsequently applied to the Greater Pretoria Metropolitan Area in 1998.

Following this successful application it has been applied in two other metropolitan areas, namely Khayalami Metropolitan Council (KMC) and the Port Elizabeth Metropolitan Transport Area, (PEMET) to assist in the planning of their public transport route networks.

This paper first discusses the need for route optimisation in South Africa, followed by a brief description of the DHV model in terms of international experience and transferring the technology to South Africa. The study objectives and applications of the route optimisation methodology in the three metropolitan areas are subsequently described as well as a synthesis of the results.

The paper finally evaluates the DHV model and the optimisation methodology in view of the lessons learned from the South African applications and recommendations are made with regard to future applications.

2. THE NEED FOR PUBLIC TRANSPORT ROUTE OPTIMISATION IN SOUTH AFRICA

The following shifts in focus of land use transport planning in South Africa have lead to the need for public transport route optimisation methods and techniques:

- The National White Paper on Transport and resulting National Land Transport Bill (3 March 1998) shifted the planning focus from providing infrastructure to mainly serve the interests of private transport to promoting and developing public transport services.

- The new Land Transport Bill requires transport authorities to develop an operational public transport plan as part of an Integrated Transport Plan (ITP).

- In terms of the Development Facilitation Act 67 of 1995 local authorities are required to formulate an Integrated Development Plan (IDP) which shifts the focus of land use planning away from fragmented and uncoordinated planning, which resulted in the current low density sprawling urban environment, to planning which promotes densification and mixed land uses in support of public transport corridors. The new spatial frameworks developed for metropolitan areas further supports the development of an optimum public transport network.

The following historic trends resulted in a large potential for optimising public transport route networks:

- The current public transport route networks have evolved in a rather ad-hoc way leading to a duplication of routes between operators and modes, and inefficient services often forcing passengers to travel roundabout routes.

- Bus routes tend to be very widespread with low frequencies resulting in rather poor services to users. For example, the average ratio of buses to routes is 1.8 in the Greater Pretoria area (morning peak) compared to an average ratio of 4.6 in Curitiba which is well known for its successful public transport system concentrated along development corridors (GPMC, 1997)

- Land use patterns have changed substantially during the last decades and public transport routes and services did not respond to these changes in an optimal way. The main forces were the trend of urban decentralisation of businesses relocating from CBD's to suburban areas, the repealing of the Group Areas Act, and informal settlements developing on the periphery of the urban areas.

Finally, the current limited government funding for transport and the huge public transport subsidy bill which is carried by Government, requires an efficient public transport system to not only save subsidies, but also providing greater value to public transport users for every cent of subsidy spent.

3. DESCRIPTION OF DHV ROUTE OPTIMISATION MODEL

The DHV Route Optimisation Model (or in short DHV-model) was developed by the Dutch consulting engineering firm DHV Consultants BV. Initially the model was developed for the urban bus company "De Lijn" operating in Brussels, the capital of Belgium. The aim of the bus company was to improve the quality of their services with the current resources in terms of budget, vehicles and drivers. The model was subsequently applied for the public transport route optimisation of the cities of Rotterdam and Den Haag in The Netherlands on main frame computers.

The application of the DHV model was boosted following the further development of the model on a personal computer platform. Following this development the model was successfully applied in various cities in the former Soviet Union, as well as Central Europe and Asia. The model was used to identify new profitable routes which would meet the demand of the public transport passengers. The model was applied through close co-operation between the transport authority and operators.

The following input information is required to apply the route optimisation model:

- A reliable origin-destination (O-D) matrix for public transport trips (train, taxi and bus);
- The road and rail networks available for the use of public transport vehicles;
- The available resources for public transport operations (budget, vehicles, drivers).

Apart from the information on the resources, all other information is normally available from conventional transport modelling studies.

To determine an optimised network it is not necessary to have knowledge of the current route structure, but this is useful in order to simulate the existing situation to determine the improvement achieved by the optimised network.

The DHV model makes use of operational research techniques to identify the optimal set of routes and frequencies to meet the demand for public transport, subject to resource constraints such as the operating budget and vehicle fleet. In the DHV model the optimisation is primarily approached from the interest of the public transport user. The main aim of model is to satisfy the needs of the passenger in terms of the reduction in the travelling time (more direct routes, higher frequency and less waiting time, etc.) and the reduction in the number of transfers.

The DHV-model consists of two main components: a simulation sub-model and an optimisation sub-model. The simulation model is a traditional 4-step transport model which can be used for matrix estimation, assignments and evaluation, similar to the EMME/2 model which is normally used for transport planning in South Africa. The optimisation sub-model generates the optimal route network in view of the specified demand.

The three main steps in the optimisation process are presented in Figure 3.1. After the assignment of the existing trip matrix to the existing route network (the reference situation) the first step in the process is the calculation of the concentrated network. The concentrated network represents the shortest paths for all public transport users, ensuring a specified minimum number of passengers per road link. The concentrated network represents the demand for bus and taxi routes. In the line generation a large number of lines are generated between each pair of existing and potential public transport terminals in the study area subject to user supplied restrictions. In the generation process, routes are identified following the concentrated paths. In this process the potential supply of routes is calculated. The final step in the route optimisation process is the line selection. In this step the most attractive lines are selected from the list of generated and existing routes. The concentrated network is used in the selection of attractive lines.

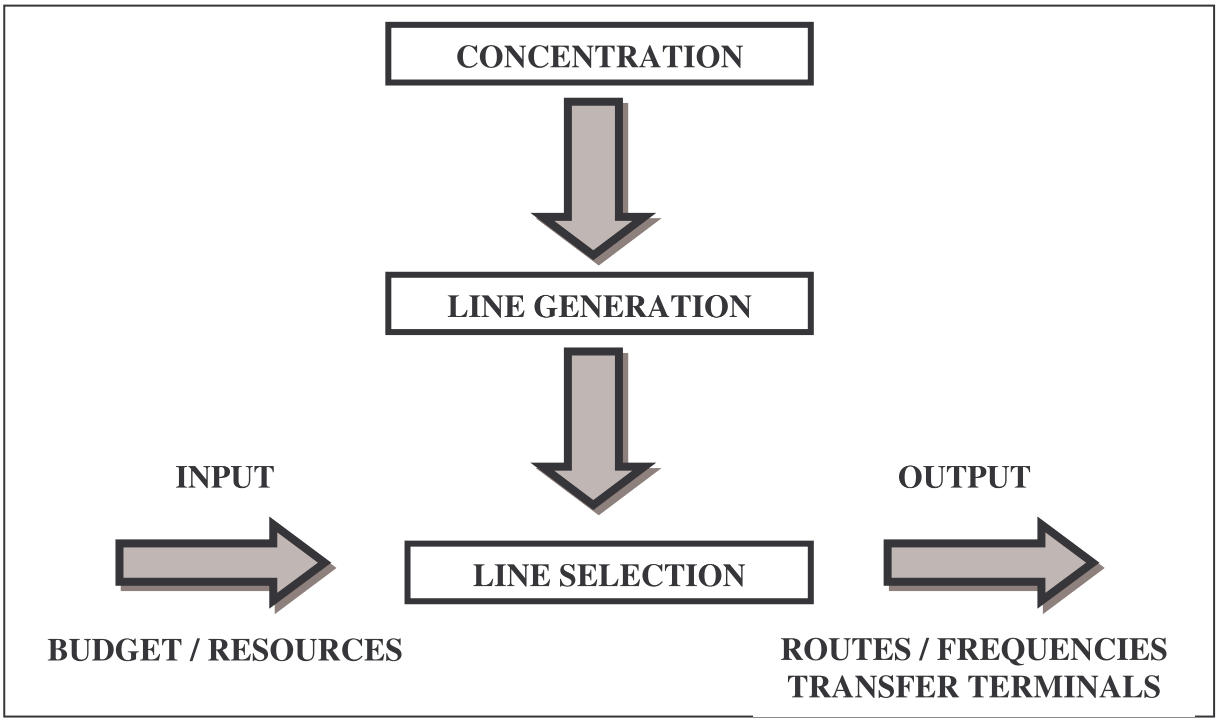

FIGURE 3.1: STEPS IN OPTIMISATION PROCESS OF DHV-MODEL

The final result of the optimisation process is a complete set of public transport routes (bus or taxi), the required frequency of each individual route and the identification of the locations where transfer terminals are needed.

It is important to state that the optimised set of routes, as proposed by the computer model, is not the final answer. The result of the optimisation process needs to be verified by the modeller and the public transport operators. The verification by the modeller is needed to both check and improve the results of the model. After the assignment of the optimised routes the modeller may have to:

- change some 2-way routes into 1-way routes (the model suggests default 2-way routes);
- change some of the frequencies if the occupancies shown in the assignment are too high;
- combine two short routes into one longer route;
- exchange some taxi and bus routes based on the loading and frequency of the vehicles.

The impact of these changes on the individual routes as well as the total network performance can be determined with the help of assignment statistics.

However, even after verification of the optimisation results by the modeller, it is still a theoretical answer. Based on previous experience with the application of the DHV-model, the best results were achieved when the theoretical results were discussed with the public transport operators. The operators assist in translating the theoretical results into a practical set of routes, ready for implementation. Ideally, the operators should be involved right from the start of the process in order to obtain their co-operation and commitment, based on an understanding of the model and its use as a tool for the optimisation of public transport operations.

Route optimisation is not applied for rail based transport. The routes and frequencies of the trains are entered in the model and are not modified in the modelling process. However, the impact of improvements to train services on the optimum road-based route network can be tested.

In order to apply the DHV model for South African conditions certain improvements were made to the source code.

Firstly the model's capacity was extended to be able to handle the extensive road network of the GPMC area. The extended model can cope with networks of up to 500 zones, 10000 links and 5000 nodes, and 500 public transport routes.

Secondly, the model was adapted to handle mini-bus taxis. This was done by allowing the specification of smaller vehicle sizes of 15 passengers, and by applying the model in a hierarchical way. The optimum bus network is first determined by specifying the bus fleet size and vehicle capacity. The model is subsequently run for a second time by specifying the optimal bus route network as fixed, and specifying the taxi fleet size and vehicle capacity.

Various parameters can be set by the user to constrain the model in view of local circumstances. These include:

- weighting the selection of existing routes
- forcing the model to select up to ten existing transfer locations
- fixing pre-scheduled routes
- specifying the number of alternative routes to be generated between each pair of terminals.

4. BACKGROUND AND OBJECTIVES OF APPLICATIONS IN THE GPMC, KMC AND PEMET AREAS

This section briefly describes the objectives and background of the route optimisation studies in the GPMC, KMC and PEMET areas.

4.1 GPMC

The purpose of the GPMC application was to determine the potential for improving the road-based public transport route network (bus and taxi) subject to the existing rail network as well as the potential for saving bus subsidies. This was also seen as the first step towards developing an integrated multi-modal public transport plan following on previous plans which addressed modes on an individual basis. A key to this plan is determining the best location of modal transfer facilities which is one of the outputs of the route optimisation process.

An EMME/2 transport model for the Pretoria Metropolitan area, (the PREMET model) was available, although this model was in the process of being updated. The available morning peak hour origin-destination matrices for bus, taxi and train were based on a home interview survey conducted in 1991 and therefore not a very accurate reflection of current travel patterns. However, the GPMC regarded the study as a first step in the process and envisaged the results to be updated following a comprehensive O-D survey which was planned at that stage.

Although the TPR2 process of data collection had not yet started in order to determine the current bus and taxi route network, a reasonably reliable bus route network was available for most bus services. Unfortunately only the main taxi routes were available, but as the focus of the study was on the bus services this was not regarded as a major problem.

Table 4.1 gives the number of peak hour vehicles and routes for each mode which was considered in the optimisation process.

Table 4.1 GMPC : Public Transport routes considered in the optimisation

MODE	NUMBER OF MORNING PEAK HOUR VEHICLES	NUMBER OF PEAK HOUR ROUTES
Bus	612	347
Taxi	1424	99
Train	33 (sets)	19

An interface program was developed to transfer the O-D trip matrix and transport network data from the EMME/2 model to the DHV model. The user friendly menu driven format of the DHV model allowed quick entering of the existing routes into the model.

4.2 Khayalami Metropolitan Council (KMC)

The main purpose of the KMC's route optimisation study was to inform the Integrated Transport Plan for the area. Although the route optimisation study addressed all three public transport modes (bus, taxi and train), taxi is the dominant mode in the area and therefore the main focus was on defining the taxi routes for the allocation of route permissions, and also to determine the best location of taxi ranks and transfer facilities.

Information on current routes and facilities provided by the Public Transport Management Information System of the KMC was updated as part of the study. An EMME/2 transport model was also available, but the public transport origin-destination matrix was outdated. The O-D matrix was therefore updated as part of the study by means of sample interviews of passengers at public transport terminals and also a questionnaire survey amongst employees at a sample of the major employers in the area.

Table 4.2 gives the number of routes by mode currently operated in the KMC area, excluding through routes with origins and destinations outside of the KMC area. Most of the buses and taxis (95 %) are operating in one direction only in the morning peak period.

Taxi services are provided by 17 main taxi associations from 25 main ranks. Bus services are provided by one operator.

Table 4.2 KMC : Public transport routes considered in the optimisation

MODE	NUMBER OF PEAK HOUR ROUTES
Train	6
Bus	23
Taxi	155
TOTAL	**184**

4.3 PEMET

The main purpose of the route optimisation study in the Port Elizabeth Metropolitan Transport Area was to inform the process of preparing new public transport contracts for tendering, to replace the current interim bus contract in the PEMET area which expires at the end of March 2000.

Data on existing bus, taxi and train operations in the PEMET area was available from the Current Public Transport Record (CPTR) which was prepared during the latter part of 1998. Table 4.3 shows the number of routes served by each mode during the morning peak period.

Table 4.3 PEMET : Public transport routes considered in the optimisation

MODE	NUMBER OF PEAK HOUR ROUTES
Bus	175
Taxi	263
Train	1

An EMME/2 transport model for the PEMET area was available, but it did not have reliable public transport origin-destination trip matrices by mode. An O-D trip matrix for bus passengers was obtained by interviewing a sample of passengers on board all scheduled buses in the PEMET area during the morning period. The sample was adjusted to a complete matrix based on the ridership figures for each sampled bus trip and using the EMME/2 model's zones. A similar process was undertaken to obtain an O-D matrix for train passengers.

It was not possible to conduct interviews with taxi passengers at taxi ranks in order to obtain an O-D trip matrix for the taxi mode, because the taxi operators stopped the surveys. The DHV optimisation model was therefore only applied to the bus and rail modes in the PEMET area.

5. COMPARISON OF ROUTE OPTIMISATION RESULTS BETWEEN THE GPMC, KMC AND PEMET AREAS

The outputs of the DHV model are provided in the following format:

i. Summary network statistics of key performance indicators such as number of routes, vehicles, operating costs, trip distance and travel time statistics.
ii. Existing and optimised route locations on the transport network.
iii. Passenger volumes on existing and optimised routes presented in tabular and graphical format (band widths and colours).
iv. Location of optimum transfer facilities and number of passenger transfers at these locations.

This section presents the network statistics for each metropolitan area and the main conclusions made regarding the set of optimised routes and transfer locations.

5.1 GPMC

Table 5.1 presents the summary network statistics for the existing (actual) and optimised routes for the morning peak hour.

In this optimisation application the vehicle fleet size was kept constant to determine the extent to which the system can be optimised with the current vehicle fleet.

The following are the main conclusions:

- The bus and taxi services are more concentrated on the optimised network with higher frequencies and subsequent reduction in waiting times compared to the existing network.
- The optimised routes are shorter (following more direct paths) on average resulting in a reduction in vehicle kilometers and operating costs.
- The coverage of the optimised network is slightly better indicated by the small reduction in walking time.
- Total travel time is reduced due to the shorter waiting times and lesser transfers.
- Passenger transfers are significantly reduced.
- Overall, with the same vehicle fleet a better quality of service can be provided at a lower cost.
- A shift from one way routes to two-way routes, although return frequencies are lower.
- In the line generation step the model generated some 20 000 possible routes.
- Of the optimised routes, 75 per cent were new routes, some of which may be similar to the existing routes.
- The model suggested a number of new transfer locations located to the south and east of Pretoria central in support of the decentralised employment opportunities.

With regard to the optimisation process followed the following comments were made by the authorities and operators in the area:

- The optimised route network provides a vision for the future, but short term solutions are also required to improve the existing situation. The need was therefore expressed to constrain the model to the existing major transfer stations to make maximum use of existing infrastructure.

- There was agreement that there is an over supply of services in Pretoria, although there was some resistance from operators to following a modelling approach.
- The route optimisation study was seen as a pilot test which needs to be taken further through the involvement of the GPMC's public transport operator forum, using the model as a tool in the decision-making process.

TABLE 5.1 OPTIMISATION RESULTS IN THE GREATER PRETORIA METROPOLITAN AREA

PUBLIC TRANSPORT SUPPLY	ACTUAL	OPTIMISED	DIFFERENCE
Route (buses & taxis)	446	240	-46%
Vehicles (buses & taxis)	2050	2050	0%
Operating Cost (R)	95 000	91 000	-4%
PASSENGER USE OF PUBLIC TRANSPORT			
Number of trips	176 870	176 870	0%
Number of boardings	318 573	284 630	-11%
Number of Passengers without transfer	61 555 (35%)	81 093 (46%)	+32%
Average Number of Transfers per trip	0,83	0,63	-24%
Average Trip Length (km)	25,9	24,8	-4%
Average Waiting Time (min)	11,3	6,7	-41%
Average Walking Time (min)	29,9	29,7	-1%
Average Trip Travel Time (min)	78,6	69,6	-11%

5.2 KMC

Table 5.2 provides the summary network statistics for the KMC area, comparing the optimised route network with the existing (actual) network. The following are the main conclusions.

- The vehicle fleet size was not constrained as in the GPMC study, and the number of routes, fleet size and operating costs of the optimised network were higher than that of the existing network. It seems therefore that the demand pattern is more diffused than recognised by the operators.

- The model indicated that there is a large shift from one-way to two-way routes, which contributed to the increase in the number of routes and operating costs. This can be explained by the fact that the KMC area has a lot of interaction with neighbouring residential and employment areas which generates two-way passenger flows.
- The optimised network indicated a large improvement in the level of service to passengers in terms of the number of transfers, walking and waiting time, and total travel time. This suggests more direct routes, higher frequencies and better coverage.

TABLE 5.2 OPTIMISATION RESULTS IN THE KHAYALAMI METROPOLITAN AREA

PUBLIC TRANSPORT SUPPLY	ACTUAL	OPTIMISED	% DIFFERENCE
Route (buses & taxi)	178	266	+49%
Vehicles (buses & taxis)	745	777	+4%
Operating Cost (R)	71 000	82 000	+15%
PASSENGER USE OF PUBLIC TRANSPORT			
Number of trips	114 483	114 483	0%
Number of boardings	197 984	147 275	-26%
Number of Passengers without transfer	56 367 (49%)	83 667 (73%)	+24%
Average Number of Transfers per trip	0,74	0,29	-61%
Average Trip Length (km)	22,3	20,0	-10%
Average Waiting Time (min)	8,3	6,3	-24%
Average Walking Time (min)	18,1	16,9	-7%
Average Trip Travel Time (min)	69.2	60,6	-12%

From an evaluation of the optimised routes and transfer locations, the following were concluded:

- The model initially assigned many passengers to routes on freeways passing through the KMC such as the N1, N3, N12 and R21, as a result of the higher speeds on the freeways. This was regarded as undesirable from a route development point of view, and also in view of capacity problems experienced on some freeway sections. The model was therefore subsequently forced to shift passenger flows from the freeways to parallel arterial routes by reducing the speeds on the freeway.
- Most of the optimum transfer locations were in the vicinity of current taxi ranks, but three new locations were also indicated.

- The model indicated a shift from rail to more direct bus and taxi routes in order to reduce transfers currently taking place on the taxi feeder routes to train. To support train, the model can be forced to utilise taxi-train transfer locations.

The route optimisation results were subsequently used to formulate a strategic public transport plan indicating the main corridors, development of new routes and public transport facilities. It was recommended that the TPR2 process be used to first rationalise services, and a phased approach be formulated to move towards the optimised network.

In conclusion, it seems that road-based public transport services need to be further developed to serve current demand patterns, and also that further scenarios be tested with the DHV model to arrive at an integrated public transport system.

5.3 PEMET

A summary of the DHV model output for the bus route network in the PEMET area, comparing the optimised network with the existing (actual) network is shown in Figure 5.3. The following are the main conclusions:

- The number of optimised routes in the peak period is about 32 percent less than the number of existing routes operated. Half of the optimised network consists of reselected existing routes, with the other half being new routes which are generally more direct than the existing routes they replace. This results in a reduction in the average trip length and trip travel time of about 5 percent.
- The model has calculated a vehicle fleet requirement for the optimised network which is 24 percent less than the existing peak period fleet. However, on some low volume routes with less than one bus load (80 passengers), only one trip has been assigned by the model in the peak hour. In practice, a more frequent service will be required and it may be preferable to allocate these routes for minibus operations.
- Examination of the proposed new routes by the current bus operator showed that a few of the roads are not suitable for bus traffic and amendments to the proposed routes are necessary. The bus operator also suggested that some low volume routes could be combined, so that ridership and frequency could be increased.

- The model indicated two new locations for transfer facilities which involved more passenger transfers than at some of the existing transfer terminals. These two new locations are close to proposed nodal developments in an integrated land use/public transport corridor that is being developed in Port Elizabeth.
- The significant potential resource savings in terms of operating costs and vehicle fleet size were achieved at the slight expense of waiting and walking times. The model can be used to evaluate various trade-offs between resource savings and walking and waiting times until acceptable levels are achieved.

TABLE 5.3 OPTIMISATION RESULTS IN THE PORT ELIZABETH METROPOLITAN AREA

PUBLIC TRANSPORT SUPPLY	ACTUAL	OPTIMISED	%DIFFERENCE
Route (buses)	175	118	-32%
Vehicles (buses)	253	192	-24%
Operating Cost (R)	53 720	42 670	-21%
PASSENGER USE OF PUBLIC TRANSPORT			
Number of trips	26 934	26 842	-0,3%
Number of boardings	35 182	34 325	-2,4%
Number of Passengers without transfer	18 992 (70%)	19 201(72%)	+1%
Average Number of Transfers per trip	0,32	0,29	-9%
Average Trip Length (km)	16,4	15,6	-5%
Average Waiting Time (min)	9,3	10,6	+14%
Average Walking Time (min)	12,5	12,7	+2%
Average Trip Travel Time (min)	54,1	52,2	-4%

6 RECOMMENDED ROUTE OPTIMISATION PROCESS

From the three applications of the DHV-model in South Africa the following process is recommended to determine an optimal integrated route network for an area and to implement the network over time.

- Like any model it is important that the DHV-model is regarded and used as a tool assisting the decision-making process of transport authorities and operators who determine the "best" route network for an area. The route network and locations of transfer facilities proposed by the model need to be rigorously tested against operational criteria and practical considerations.

- Operators should be involved early in the process to obtain their commitment to assist in translating theoretical results into practical solutions. The optimisation process in Port Elizabeth demonstrated the benefits of involving the operator from the start. However, operators will at least need to indicate a willingness and openness to participate in the process.
- The DHV-model is not competing with the EMME/2 transport model used by metropolitan authorities in South Africa. The two models are mutually supportive and it is in fact recommended that the two models are used together. The strength of the EMME/2 model is to simulate demand for a given supply of routes and services, while the DHV-model provides the optimum supply of routes and services for a given demand. It is also important to note that the DHV model addresses only one component in the planning and design of public transport services which also involves the design of time tables, vehicle and crew scheduling. Figure 6.1 gives a schematic presentation of the interactive use of the DHV and EMME/2 model, and the role of the DHV model in the whole process of planning and design of public transport services.
- The current TPR2 process which assesses existing demand and supply patterns in order to remove duplication and adjust over and under supply of services more in line with demand, is only the first, but necessary step in the optimisation process. The next step is to determine reliable origin-destination patterns and to evaluate alternative network scenarios maximising level of services to passengers subject to resource constraints. An optimisation tool such as the DHV-model will play an important role in this phase.

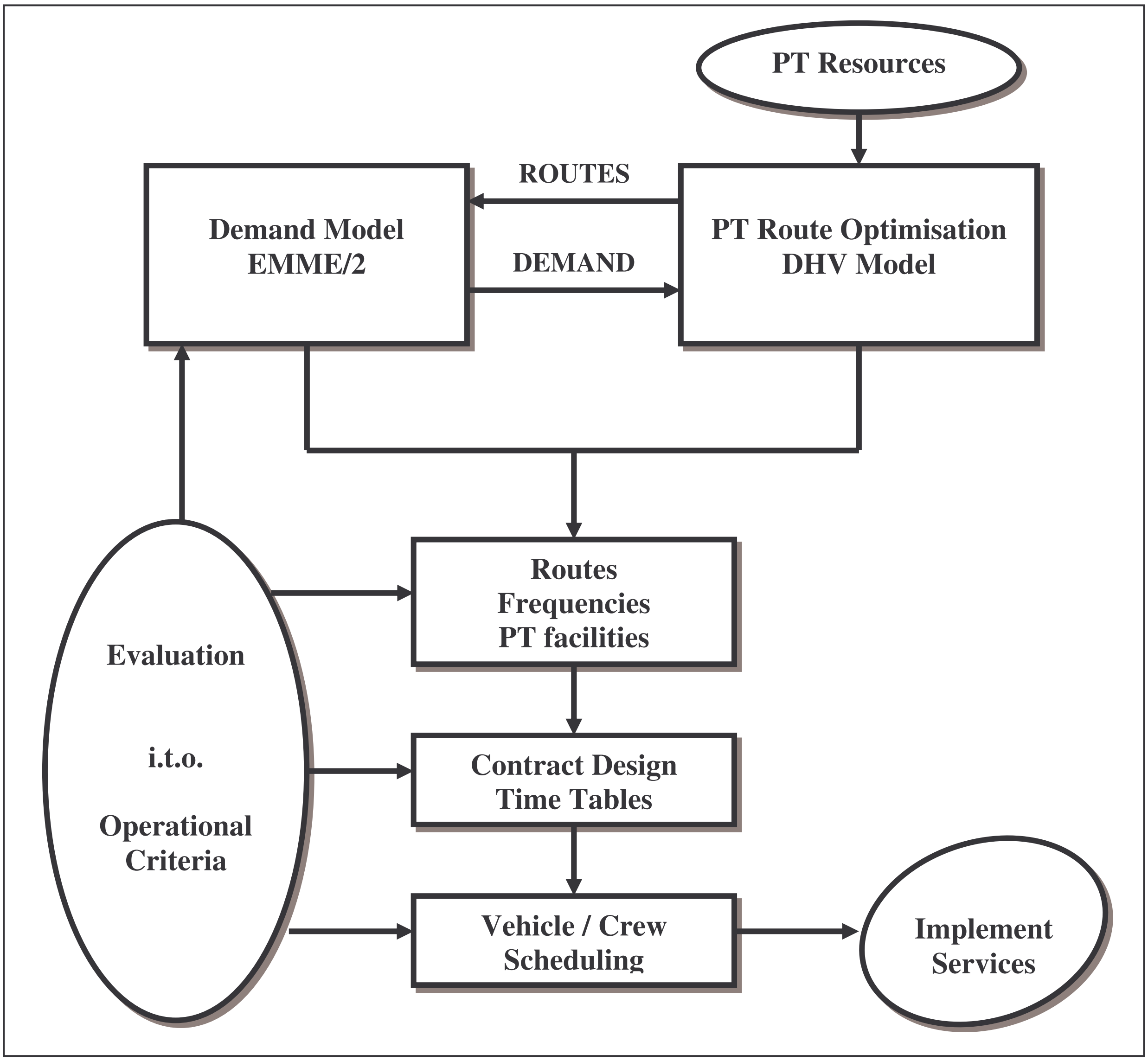

FIGURE 6.1: ROLE OF ROUTE OPTIMISATION MODEL IN PLANNING AND DESIGN OF PUBLIC TRANSPORT SERVICES

7. CONCLUSIONS AND RECOMMENDATIONS

This paper described the application of the DHV public transport route optimisation model in three metropolitan areas in South Africa. The distinct results of the model responding to the various demand patterns in the three areas demonstrated the role and benefit of the model. In view of the lessons learned from the three applications, recommendations are made with regard to the current rationalisation and optimisation process embarked upon by metropolitan authorities.

For transport authorities to seriously address the public transport problems in South Africa they will have to focus on operational tools such as the DHV-model in addition to infrastructure planning tools which they traditionally utilised . Accurate information on travel demand patterns is crucial in this regard. There is a critical need for authorities to update O-D travel information which has become out-dated. Certain authorities have already taken the lead in this regard.

Finally, existing transport network models in South Africa do not simulate multi-modal trips and the current inefficient public transport supply patterns adequately. This may be the reason why the route optimisation studies have shown less than expected resource savings in some instances. For the evaluation of alternative integrated multi-modal network scenarios the accurate simulation of multi-modal trips will be essential.

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