# THE CONCEPTION AND DEVELOPMENT OF AN OPERATION CONTROL SYSTEM FOR FLEXIBLE MODES OF OPERATION

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## 1. INTRODUCTION

A control system for a flexible means of transport signifies a further development in a personalised bus system. With the on demand bus system, passengers give their destination by means of a call box such as public or private telephone or by means of a central computer. The computer is familiar with the location and planned routes of the buses, and is therefore able to establish which bus is in the best position to reach the required destination and advises the bus of its final route by means of radio transmission. The location of vehicles is followed and controlled by means of logical localisation similar to that of the public transport network. Flexible transport means that the vehicles can be deployed in different ways depending on the time of day and area covered in other words on-demand, either within the existing network or route deviation, which is a cross between the demand and the line haul mode.

Commissioned by the Minister for Research and Technology, Rufbus GmbH, is currently developing a new software for the deployment and control of buses using flexible transport means, which is based on the experiences of the on-demand bus system Retax in Wunstorf (MBB) and Rufbus in Friedrichshafen (Dornier-System). The above companies were given the job of developing this system. New software became necessary because the current software was not able to cope with the increased demands on the system. The expansion of the software should increase the flexibility of the system and thus improve the viability and service offered.

## 2. SYSTEM FUNCTIONS

The system can be seen in it's entirety in Fig. 1. The means of transport used is irrelevant.

The centre of the system is the computer which gathers and controls all system data. Part of this are the transport requests (requirements) which are fed into the system by various means of communication. This repeats an essential point i.e. passengers must make their requirements known to the system. They must inform the computer of the desired point of departure, destination and time of day.

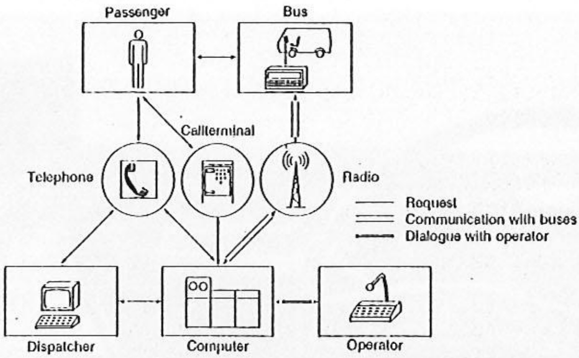


Fig. 1 Demand-Bus-System

They can do this at can terminals which will be set up at used bus stops (Fig. 2) or by means of telephone and a controller who informs the computer of required route via a terminal.

Fig. 2 Call-Terminal RETAX

It is planned that the information be fed m-to the computer directly by automatic spealer.
Standing orders and advance bookings can be made (to the control centre) by telephone or in writing.
Another means of application is in the vehicle ibelf. The buses are connected directly to the computer via radio transmission. Information is conveyed by a terminal in the bus with a display and keyboard (Fig. 3). This equipment is also used to advise the location of the bus and to give instructions to the driver which route to follow.
On the basis of the new route requirements and location of the buses and with the help of an optimising system the computer can deade which bus can best meet the new transport request and also determines how the new departure point and destination can best be incorporated into the existing route.

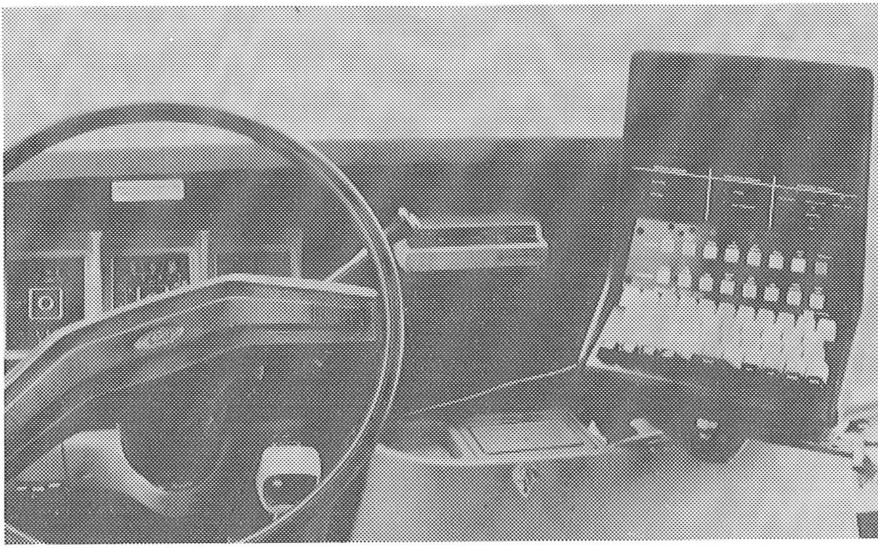

Fig. 3 Vehicle-Terminal RETAX

This route is now transmitted to the bus by radio and displayed to the driver. Arrival at the bus stop is established either by input from the driver or the criteria of a door opening or shutting in conjenction with logical criteria such as an odometer or travelling time, so that the location is not incorrectly transmitted should the doors be opened or closed in between bus stops.

Depending on the operational concept their are various possibilites of processing at the bus stop ibelf. It is planned that the destinations of all alighting passengers be given into the bus terminal equipment. The bus driver can thus check whether all passengers who have requested transport are present. Passengers who have not got onto the bus can be identified and reported to the computer.
The computer deletes the requested journey from the list and if necessary alters the route should no other passenger wish to alight at the cancelled destination. The computer removes that point of the route and ties up the loose ends again.

Another important extension of the system compared to existing systems is the supervision of transfer procedures.
These transfer procedures come into being when the bus fleet is subdivided in areas ie. when each bus only covers part of the bus stops. A subdivision of the fleet into zones can serve a purpose because the volume of traffic varies in the different areas. Furthermore, this form of structuring in conjunction with transfer procedures increases the collective travel requests and likewise the bus productivity. How this is carried out by means of transfer procedures in described in Section 4.
The calculated transfer procedure can be supervised automatically by the system if a feeder bus is late. Incidentally, it should be mentioned that such surveillance of connections necessitates a high level of software in the realization phase.

Incorporating other forms of operation and integrating differing forms of operation also serve to increase the vehicle and thus the system productivity. The line with its extreme bunching effect is capable of coping with a high volume of traffic, too, even if in general with a poorer level of services than in the case of ondemand control.
The route deviation mode presents itself for two reasons. On the one hand, this mode of operation combines the advantages of line haul and the demand mode in view of a certain volume of traffic, namely in the one instance a high degree of convergence and, furthermore, a good level of service with minimum walking and waiting times. On the other hand, advance information concerning the traffic flows occurring can be utilized when establishing the route deviation.
The different forms of operation which are feasible in the BFB system are illustrated in Fig. 4.

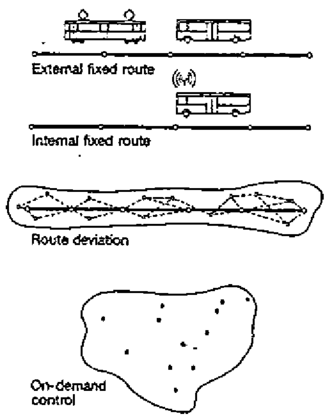


Fig. 4 Modes of Operation BFB

It should be noted that lines can also be incorporated which are not in radio contact with the computer. These lines are termed external lines. Surveillance of the connections is not possible in this case and, moreover, the schedule situation of the vehicle upon dispatch cannot be taken into consideration; the nominal timetable must be taken as a basis. An example of a BFB mode of operation model is shown in Fig. 5.

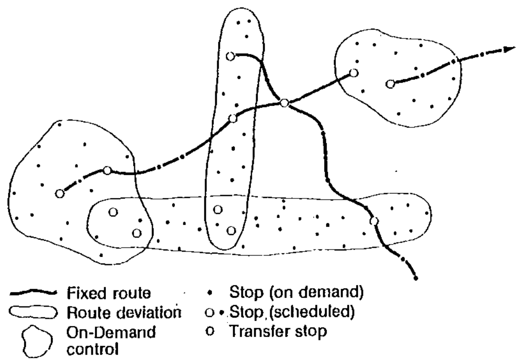


Fig. 5 Model of Modes of Operation BFB

Further supplements and extensions to the system relate to the operational behavior. For instance, automatic system control should be created in case of deviations from defiried nominal statuses. Furthermore a Strategy should be drawn up for handling disruptions in the system. Can this be explained by means of an example. The control establishes that the average waiting time exceeds a nominal value in a certain zone. It is now endeavoured to control the waiting period for an intermediate time to below the nominal value by changing parameters and the boundary condition for the objective function. If this is unsuccessful, or if the waiting time exceeds a maximum value, procedure for handling disruptions is initiated. In the simplest case, the incident is reported to the dispatcher. In a further step, the computer can then provide the dispatcher with descision-making aids. In a final stage automatic treatment of the disruption is possible. In every case the disruption is automically or semi-automatically recorded and evaluated.

Thus a further point has been mentioned, namely the improved feasibility of operational evaluation, in particular a strategy, too, for the detection, documentation and elimination of failures occurring in the course of operation.

Finally, it should be mentioned that some important extensions are being implemented with respect to the operating data, namely a disinction between subnets, times of day, an so on, as well as consideration of factors such as the effect of weather and traffic conditions, including operational characteristics such as vehicle and driver schedules for several days in advance. These and further requirements were drawn up as the basis for software preparation by a study group composed of various operators, developers und other institutions, and compiled in the form of a technical specification.

## DESCRIPTION OF THE SOFTWARE STRUCTURE

Apart from the purely operational requirements, requirements were also established in the technical speciafication relating to the software engineering side, such as conceptional definitions, hard- and software environment, programme language, development control and test procedure as well as design and documentation procedures.

Basically, the new software should be easier to maintain than the previous version and should be extensible. For this reason it was agreed to draw up the BFB software in the programme language PASCAL and not, as previously, in FORTRAN. The computer-supported procedure EPOS is used for design and documentation purposes, which is insofar of significance as the software is prepared decentrally. A VAX 750 computer made by Digital Equipment with a 2 MB memory is employed.

A functional top-down design was prepared on the basis of the technical specification, yielding essentially the following functional or modular structure, respectively:

- Communication with the vehicles, processing the location reports
- Communication with fixed booking and information equipment
- Communication with the dispatcher
- Determination of routes
- Realization of routes using the submodules
  - on-demand control
  - route deviation mode
  - line operation
- Cancellation
- System control
- Incident handling
- Processing permanent orders
- Optimization of route point sequence
- Start of operation, restart and end of operation
- Statistics
- Editors
- Simulation for the purpose of operational preparation and planning
- Software control
- Data managemant.

The last two packages differ qualitatively from the previous ones. They were deliberately added to the list in order to permit central processing of real-time control and data management and to avoid duplicating work. Over and above this, central data management was self-evident, since the major part of the data is extremely closely interlinked.

Thies functional structure was then converted to á software-oriented process structure (Fig. 6), one process being assigned to each data channel.

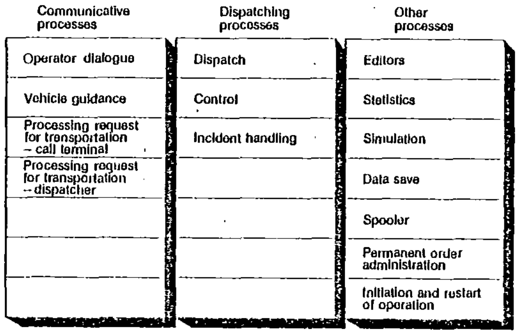


Fig. 6 Process Structure BFB

Naturally, actual routing is of central significance among the planning processes. The structure of the routing process is shown in Fig. 7.

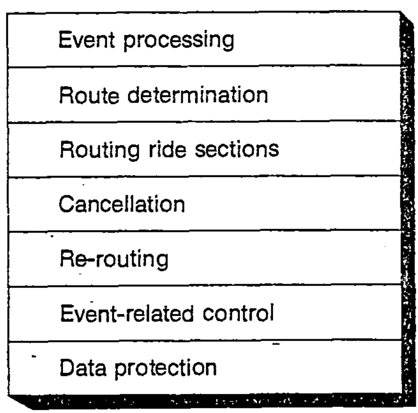


Fig. 7 Modul Structure Dispatch Process

## DESCRIPTION OF THE ROUTING PROCEDURE

The main features characterizing the routing procedure shall be explained in the following.

The requests for transportation reaching the system via the different communication channels are filed to form a queue pertaining to the routing process. The next request for transportation to be processed is taken by the routing process from the queue. Actual routing takes place in two stages.

During the first stage, routes in the form of travel section are determined for a request for service. One travel section represents the journey ride in one zone with one bus without any transfer. The travel section are interlinked by means of the transfer processes and together give the respective route.

The number of possible different routes is defined by the data base, in particular by the interlinkage of the zones. The possible alternatives are evaluated and put into an appropriate order of sequence. The evaluation for the on-demand bus ride sections is carried out on the basis of anticipated values for waiting, transfer and journey times and for line haul and the route deviation mode an the basis of static timetables. The evaluation includes determination of the expected transportation times.

Depending on the computer load, the travel section are then assigned to one or several routes of perticular vehicles. If there are several routes, processing will be carried out in that order which is produced from the destination value. Assignment to the vehicles for the demand mode is carried out by means of an algorithm which examines all possible points of entry along the bus routes and takes into consideration boundary conditions (e.g., regarding waiting time, detour made by the vehicle). These can be listed however, given certain prerequisites.

All the preplanned route points and the previous stops are contained in the lists. Basically, the bus is located between the previous stop an the next route point. This includes the case when it is already located at the next point and the passengers alight and descend. Hence no new point can be incorporated between these two points. The starting point can only be incorporated after the next point. Fig. 8 illustrates the diverse incorporation possiblities to be taken into account.

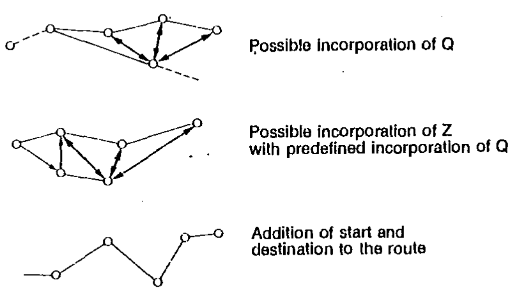


Fig. 8 Possible Incorporation of Start and Destination

The following are to be considered as special cases:

1. The incorporation of start and destination behind each other
2. Addition of the destination
3. Addition of the start and destination (Also as a special case with respect to point 1)

In order to describe the network, that is, to pre-plan the ride times, the routing process requires a matrix in which the times between all the points are shown. As far as operation is concerned, the direction of the buses in each section must be taken into account, since the section ride times can differ here very considerably, due to the fact that as a rule the bus cannot turn round in the section and must make additional detours if facing in the wrong direction.

A distinction can be made in the case of the objective function between user parameters and system parameters. The various times accruing upon transportation are of primary interest to the user:
- walking time
- waiting times
- ride times
- transfer times

These together form the journey time.

System parameters for the demand mode, which may be incorporated over and above this in the objective function, constitute:
- detours
- detour time
- working to capacity
- deadheads.

In addition, the following accrue when new routing is effected for the passingers already provided for in the relevant vehicle:
- Additional waiting times, when a passenger already provided for has to alight after the new passenger
- additional ride times due to new detours.

The objective function of the ondemand bus system constitutes four components, which are considered for the respective time of dispatch.
These four components were selected on the basis of preliminary investigations:

1. The waiting time of the new customer
2. The ride time of the new customer
3. The bus detour (or detour time)
4. The journey time of the passengers already on the bus in question, taking their direct travel time into account.

Functions present themselves for the operation of an on-demand bus system which in certain areas bear the linear connection in mind an in other areas considerably affect the operational flow, polynomials of the following form (Fig. 9):

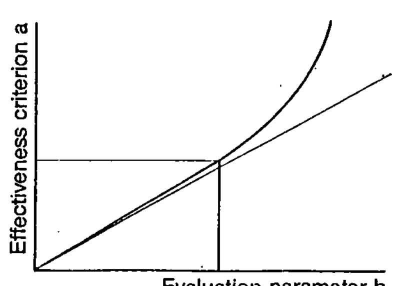


Fig. 9 Evaluation Function

$$W = a \cdot (G_b/b + (G_b/b)^{c/d})$$

The value W = a is assigned to the value G = b. The maximum deviation from the linearity in the area $G_b$ b is a/d. The deviation exceeding b can be influeced by the exponent c (progressivity).

The objective function of the ondemand bus system is yielded as:

$$Z = \sum_{i=1}^{n} W_i = \sum_{i=1}^{n} a_i \cdot f(G_{b_i})$$

The following aspects are taken into account for the allocation sequence for the request for transportation:

On the one hand, realization of the individual travel section should be attempted in the first instance for a small time interval only. Most cases are covered successfully in this way and computing time is saved. On the other hand, no routes, if possible, should be completed according to minimum quality criteria, if the route or sections there of cannot be realized in the first step. Iterations are hence envisaged, namely by easing the boundary conditions relating to time and by altering the sequence when handling the individual ride sections. The intention is to avoid subsequent rejection of already assigned ride sections, if one ride section cannot be realized.

The following principles apply to the allocation of ride sections for the demand mode:

- Times at bus stops are flexible within the scope of tolerances, which can be predefined, with regard to the assurances made to the passengers. These tolerances can be selected in a larger range by the operator.
- Bus delays are taken into account, and allocation facilitates the reduction of delays.
- The bus-stop sequence can be altered subsequently by means of sequence optimization, as lang as no guarantees are broken in doing so.
  By means of the evaluation function special preference is given to high productivity of vehicles and collection capactity.

The realization of the route deviation mode and of line operation differs from the above-described procedure.

The operational planning department draws up and processes timetables for the route deviation mode, filing them on data carriers by means of editor programmes. These data are converted on operational initialization to form up-to-date bus routes. These routes are handled during the routing procedure like normal on-demand bus routes with the following exceptions:

- own objective function
- own boundary conditions
- "travelling backwards" is avoided.

The routes are optimized subsequently. "Travelling backwards" is avoid ed by chacking distances or ride times from the network matrices in such a manner that a point to be incorporated, must not be further away from the next pregiven route point than the point after which it is to be included in the route.

In addition to the functions described, it is possible to cancel bus stops from the route which were pregiven, but for which there is no request for transportation (as origin or destination). For this purpose, the vehicle management checks whether a stop which, according to a location report from a vehicle, is to be handled by this vehicle, is linked to ride sections or not. If this is not the case, the bus is not commissioned with this stop, and appropriate cancellation is effected. This procedure cannot be applied if there is no compulsion to book at the respective stop.

A ride strategy exists to determine the departure signals, which in certain circumstances is modified in comparison with on-demand control. This ride strategy, however, no longer alters the sequence of the stops to be approached.

Special static timetables are drawn up for line haul and filed in a particular data format, in order to store the timetable and save space in large service areas with a high line share.

The times realized are entered by the different modules in the route and ride section list, and transmitted for statistical purposes subsequent to actual transportation.

The above-described procedures are based on the experience gained with the Rufbus and Retax systems, but necessitate, however, a completely new data format in view of the expanded requirements.

## FUTURE PROSPECTS

The project schedule envisages software integration by late 1982, and overall integration by May 1983. In consequence, simulation results relating to operability and real-time behaviour should also be available by late 1982. It will be possible to provide a report on this in April 1983.