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Optimising Route Weighting in Telecommunication Networks using Fuzzy Logic

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Abstract. Automatic route search in telecommunication networks will be very important in future. Numerous technical and economic aspects have to be considered when choosing a route in a transport network. Fuzzy rule bases offer an excellent opportunity to take all essential aspects into account when evaluating possible routes. A shortest route strategy for transport networks is presented, which is based on this technique. The results demonstrate that once established the network quality is preserved when using this method for route selection in transport networks.

Keywords: Fuzzy control; Neuro-fuzzy systems; Telecommunication networks; Transport networks; Route optimisation; Shortest route strategies

1 The application area

The importance of telecommunications networks has increased dramatically in recent years. As a result of growing public and corporate dependence on these networks, high availability and reliability have become key issues. Due to market competition the operators of transport networks, i.e. telecommunications companies, are forced to make optimum use of their networks. Therefore a lot of time and money is invested in configuring and planning transport networks, with both transport-specific network dimensioning and cost optimisation playing key roles [9]. As a result the transport network can be viewed as a system, which is optimised under technical as well as economical aspects. The long-term goal is to preserve this optimal state.

However, a transport network will be changed during operation: the capacity of the communication lines is adapted to meet market requirements and maintenance activities have to be performed. To fulfil these tasks so-called switching actions are executed. Switching actions are used to create new link connections and also to switch over and re-route link connections. For every switching action a route has to be chosen for the new connection line. These switching actions change the network structure. However, it is economically and technically essential, that the optimal state of the system is guaranteed.

The transport network can be represented as a graph. Parameters describing the current state of the network are stored at the edges and nodes of this graph. To perform a switching action a route has to be chosen. This choice is made using the graph representing the network structure. Historically, experts at the switching center chose routes using their own rules. But the time per switching action is decreasing more and more. On the other hand the number of switching actions to be handled in a given time span is increasing. Telecommunication management networks (TMN) are used today to carry out the varied tasks that arise during the operation of a transport network. With that technology, shortest path routing strategies are being used. These shortest path routing strategies use a measure or metric calculated using one selected parameter. The traditional shortest path algorithms, like for example Dijkstra [1], use this metric to determine the shortest route. Descriptions of procedures that improve these traditional algorithms using neural networks and fuzzy logic can be found in the references listed at the end. However, these procedures also require a metric for the edges [3],[7],[8].

If this metric does not take account of all important aspects, then the changes made to the transport network as a result of the route choice can disrupt the well thought-out network configuration. The aim of this article is to present a routing method that best preserves the quality of the transport network.

2 Identifying and constraining the task

A transport network can be represented as a set of network nodes that are linked together using various media. Network nodes represent the points of receipt and dispatch for the data. The various media and protocols used in these networks do not play a role in this investigation.
A transport network is structured hierarchically. Channels of lower transmission speeds are embedded in higher-speed channels through multiplexing. Each transmission speed thus gives rise to a subnetwork providing channels for this transmission speed. If a transmission line for a particular transmission speed is to be switched from a source to a destination, a route is chosen in this subnetwork. Knowledge of the routing of the channels in the higher and lower hierarchies can also be important when choosing a route. This and associated issues will not be investigated here. For the task only one subnetwork is considered. It is assumed that all data for the route choice is available in this subnetwork. The influence of the hierarchical structure is worthy of further study. The aim here is to improve the quality of this subnetwork.
So for our task we can consider the transport network to be a graph in the mathematical sense of the word. The solution presented here considers the following definition of the graph:
An edge in this context refers to the logical combination of all channels that have the same endpoints and the same transmission speed. The nodes of the graph are the endpoints of the channels. These nodes can be network nodes based on synchronous digital hierarchy (SDH) [6] or on plesiochronous digital hierarchy (PDH) but also an administrative clustering of equipment.

3 The Fuzzy Rule Base for Edge Weighting

3.1 Motivation

As mentioned above, the edges of the graph representing the network structure have to be weighted with a metric to use classical routing algorithms. For this weighting all route choice aspects that are relevant and available should be considered. The information available for route selection in a transport network are:

- the parameters stored by the telecommunication management network
- the knowledge and the empirical rules of the experts in the switching centres
- rules used during planing and configuration of the network

All shortest path routing strategies use one parameter to determine the path. Different strategies use different parameters. But the choice of route may not only be based on one parameter. This problem already H. Hellendoorn mentioned in his article [5] for a routing decision for Call Admission Control programs for broadband ISDN-networks.

Experts' knowledge and the requirements of the planing phase are available in the form of rules. Fuzzy logic is an excellent heuristic method to translate rules into a program for computers. This method enables us to formulate the rule and knowledge we have and produce a fuzzy rule base and a fuzzy controller. This fuzzy controller is used as a mapping function from the multidimensional space of the edge parameters to the single dimensional space of the real numbers. So the fuzzy controller "calculates" a real number for every edge, the so-called edge value and so provides a weighted graph for the route selection.

The rule system for weighting the edges incorporates all the relevant aspects. We aim at a rule system that can at least preserve the optimised configuration of the transport network if not improve it in comparison with the traditional procedure.

In order to choose the route, the customer type for whom the line is to be provided must be considered. It may happen that a high cost line will be used in order to achieve high quality transmission. Different selection criteria come into play for the edges used in this case than for edges of lines which cost less but do not guarantee high quality. This leads to a classification of routes, whose edges are to be weighted for the choice process. A separate rule system is proposed for each route category.

3.2 Architecture

The fuzzy rule base defines a mapping from the multidimensional space of the edge parameters to the single-dimensional space of real numbers. This will be done in a in such a manner as to produce an edge metric using which the Dijkstra algorithm can be applied.

The weighting of edges takes account of economic and operational requirements, but these requirements are assessed differently.

Fig. 1 shows the weighting of edges in a schematic diagram. In general, the smaller the edge value, the more likely it is that the edge will be selected. The routing algorithm minimises the sum of the edge values in the path.

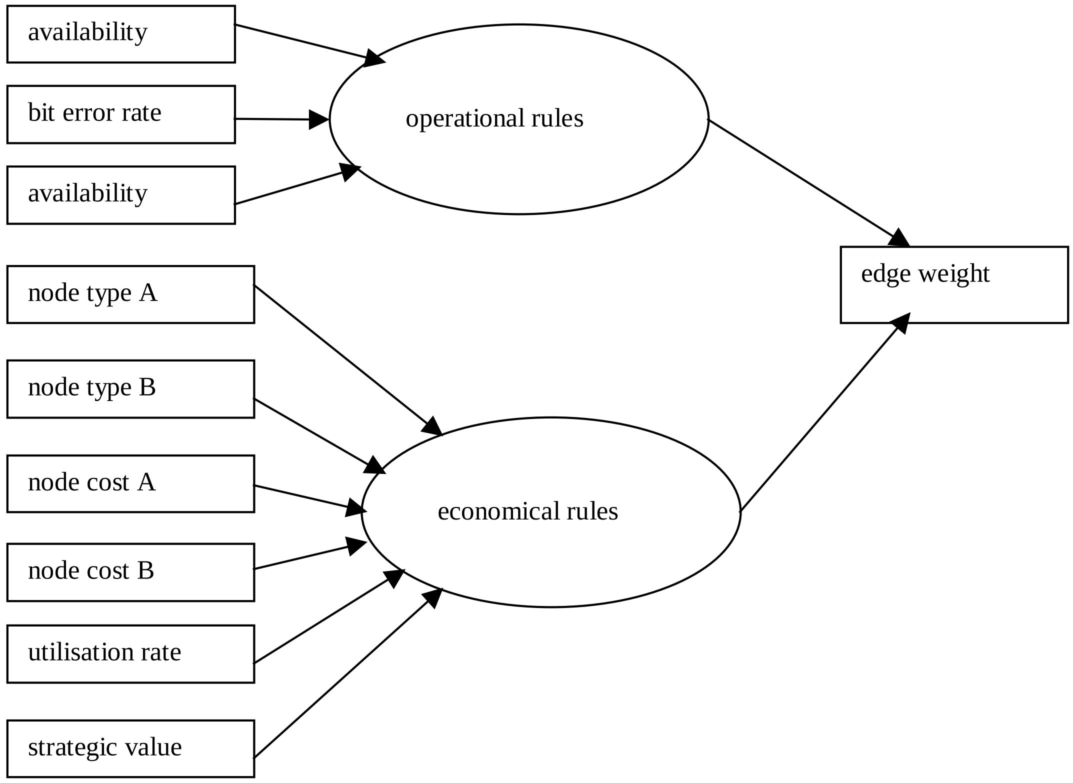

Fig. 1: Structure of the fuzzy rule base

The Fig. 2 shows the architecture of the system. For every edge the parameters are put into the fuzzy rule base, the rule base produces a real number for that edge. When all edges are treated the weighted graph is ready for the work of the “Route finder”.

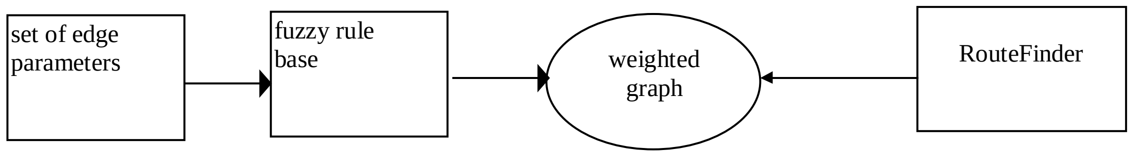

Fig. 2: Architecture of the system

Since each route that is found and used changes the edge parameters, the fuzzy system must subsequently weight the graph again. It remains to be investigated whether this is essential after each individual route selection. The graph might be very big, so the change of the parameter “utilisation rate” is not significant when one route is used in this network. Additionally the weighting of the graph will take some time. So when using this system commercially the graph may have to be weighted perhaps every night or once a week. This depends on the actual data and the number of records that have to be considered. In order to be as precise as possible the graph for the testing system will be weighted every time a route is chosen and marked as used.

3.3 Advantage of the method

The system for edge weighting presented here incorporates the results of analysis as well as the knowledge of experts. So we are using all aspects for the routing decision.
The user, here the telecommunication company, is able to assess the rule base because he does not need special IT know-how to read and understand the rule base.
Should the conditions governing the edge weighting change, perhaps because the technologies used or economic requirements change, the rule system can be adapted accordingly. Consequently the rule base must be changed but not the program itself. This is another great benefit of this technology.

4 Validation

It is necessary to validate the improvement in transport network quality using fuzzy routing method instead of traditional procedures. But of course there is no definition for “quality of transport network” in the literature. It goes without saying that only those aspects can be improved that used during the route choice process. The main aspects taken in account here are cost optimisation and utilisation.
The calculation of routes costs is correlated to the rules for choosing a route. It is obvious that telecommunication companies whose routing costs just depend on the physical length do not need to use a lot of rules for making their routes choices. If one parameter, say physical length, is responsible for cost, then this parameter has to be minimised and nothing else. But if a set of rules is necessary to make routes choices then these rules represent the most important part of the cost calculation. Consequently the edge value, which is calculated using the fuzzy rule base, measures cost.
The results of the simulation show, that costs for routes, which are determined using this system, are less than routes, which are determined by minimising hops or physical length.
The results of the simulation also show that the system prefers nodes and edges whose utilisation rate is medium. That is exactly the fact which is required in the fuzzy rule base.

5 Simulation Results

5.1 Application

It is self-evident that route categories and the associated fuzzy rule bases depend on the respective operators and their network specifications. This data is extremely confidential. So even if a telecommunication company were to provide data and the corresponding rules, it would never agree to publication. Therefore a transport network simulation is used to avoid the problems with confidential data. A fuzzy rule base is designed for routes that place considerable demands on the quality of the transmission line. These are termed high-priority routes. If it is possible to solve the problem for this test configuration it is highly likely that it will work for a real application too.
A MS® Windows™ application called NetRouty was implemented to create and handle the graph representing the transport network using a graphical user interface.
NetRouty can create and modify graphs, chose routes, calculate the cost of the routes and observe the utilisation of the graph. The weighting of the graph is done by a server application. This is a command interpreter for the handling of Fuzzy Rule bases and Neural Networks. The procedure developed by A. Bücherl was used and extended to produce the fuzzy controller for edge weighting [2].

5.2 Graph and Fuzzy Rule Base

To validate the postulation, a graph with 78 edges and 37 nodes is created. In the fuzzy rule base edges are preferred which are physically short and nodes, which are cheap and can be controlled remotely. Because a fuzzy rule base for high priority routes is to be created a minimal quality has to be guaranteed for the edges used in the routes. Here, admission quality is measured using the parameters *availability* and *bit error rate.* If a customer asks for a high priority line he knows that the *bit error rate* is less than a specific value, MAXERR and that the *availability* is higher than a specific value, MINAVAIL. The following must be considered for both parameters:
the customer's priorities diverge from those of the operator, but the operator has to take account of his customer's priorities. As an example the parameter *availability* is discussed here in detail.
To be sure that the customer will get the quality he ordered, the rule in the fuzzy base is: prefer edges whose *availability* is higher than MINAVAIL. But this rule only expresses the interests of the customer. The higher the availability of the line has to be, the more time the operator has to invest for maintenance. So the selection of edges for that route will prefer edges whose *availability* is only a little greater than the MINAVAIL. Edges whose *availability* is less than MINAVAIL will be excluded, because otherwise the quality would fall below the value ordered. Consequently, the customer might stop recommending the telecommunication company and will look for another operator. This would be very bad publicity.

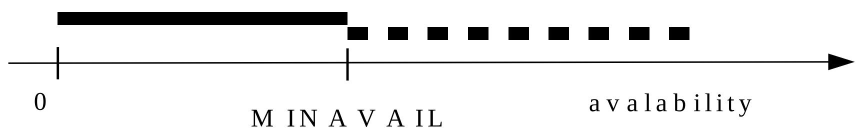

Fig. 3: Area of availability

In Fig. 3 the black line shows the range of *availability*, which is unsatisfactory and the dotted line shows the satisfactory range.
The goal is a uniform utilisation in the transport network. So edges and nodes are preferred whose utilisation is medium. Edges and nodes with very high utilisation are avoided, because the 100% usage of

one edge can lead to specific nodes becoming unreachable. On the other hand nodes, which have a very small utilisation, are avoided too. For under-used nodes it can be useful to remove all traffic from them. The hardware of that node can be used at a different geographical location, where demand is greater.
If the graph is extended by adding a new node or an “old” node, which is no longer used at its original location, then this routing method will never choose it because the *utilisation* of this node is too small. To resolve this problem a further parameter is added to the list of parameters, called *strategic meaning*. If the value of this parameter is high the edge is preferred. So the user can use the parameter *strategic meaning* to force the system to prefer this node. See the example in chap. 6.4 for details.

5.3 Calculation of costs

The revenue from a route is the same regardless of whether classical or a fuzzy based route selection is used. So the cost of making particular routes available has to be considered.
A route is a sequence of edges. The calculation of edges costs is correlated to the rules for choosing an edge. The cost of the edge is represented by the edge value. We define the cost of an edge to be the edge value plus a penalty if the quality is less than ordered. The cost of the whole route is the sum of the costs of all edges.

5.4 Results

It is obvious that sufficient routes, which are good in the sense of the rule base as well as a sufficient supply of route choices are needed. We cannot find optimal routes if we do not have any in the transport network. If nodes with low utilisation should not be used then they may not be taken as a sink or source for a route.

The Fig. 4 shows a part of the graph, which represents the network. The numbers at the edges are the edge values calculated by the system with the parameter *strategic meaning* set to 5. There are three different edges from the city of F to the city of Lyon, because there nodes, *Lyon, Lyon2* and *Lyon3* , are positioned in the city of Lyon and one node *F* in the city of F. Tab.1 shows the parameters of these edges and the edge values.

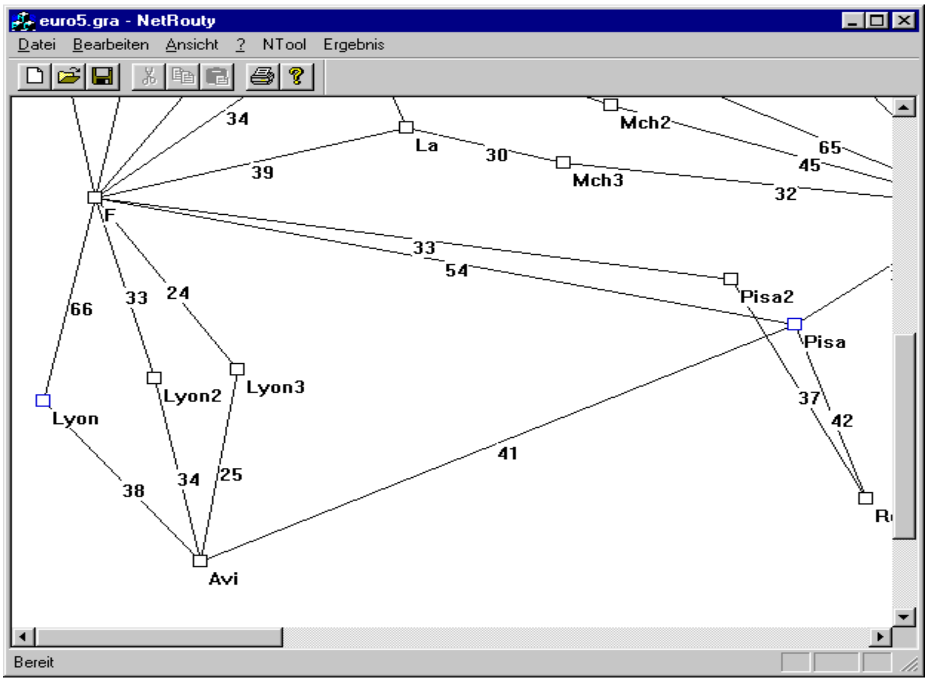

Fig. 4: Section of the graph

The nodes *Lyon2* and *Lyon3* are very similar. They are remotely accessible but have different utilisation parameters. The node *Lyon* is not remotely accessible. The node parameters are listed in Tab.2.

	F→Lyon3	F→Lyon2	F→Lyon
strategic meaning	5 / 1	5 / 10	5
availability	80	80	40
total capacity	70	70	50
used capacity	60	2	40
bit error rate	20	20	80
length	167	149	165
delta availability	20	20	-20
delta-bit error rate	20	20	-40
edgeValue	24 / 32	33 / 26	66

Tab. 1: Parameters of the edges

	F	Lyon	Lyon2	Lyon3
node class (*)	1	0	1	1
utilisation	50.8	65.0	2.9	79.2
node cost	30	80	50	50

Tab. 2: Parameters of the nodes

(*): 1 means remote accessible, 0 means not remotely accessible.

The system will prefer the edge F→Lyon3 because the quality is right and the utilisation also. If the edge F→Lyon2 should be used despite its low utilisation, the parameter *strategic meaning* can be changed as shown in the table and the system will prefer it instead.
By changing the parameter strategic meaning in the above described way the user can force the system to choose empty edges and nodes without changing the fuzzy rule base. When the utilisation rate of these edges and nodes is grown to a medium value the user can reset the parameter *strategic meaning* of these edges and nodes. Subsequently uniform utilisation can be selected.

The next tables show routes and their cost. The definition given above was used to calculate the costs.

route chosen by fuzzy routing system	cost of the route
HH#Kiel2#Rost#Danzig#Mo	177.00
HH#Kiel#Krakau	244.00
HH#F#Pisa#Ro	132.00
HH#F#Pisa2#Roma	106.00
Tr#F#Pisa2#Roma	100.00
Tr#F#Pisa#Ro	127.00
Tr#Bn#DA#Nb#Pa#Athen	165.00
Bn#DA#Nb#Ro	106.00
Bn#Tr#F#Lyon3#Avi	112.00
F#Pisa#Ro#Pa#Athen#Samos	189.00
F#Pisa#Ro#Pa#Mo#Thes2	203.00
F#Pisa#Ro#Pa#Mo	161.00
Bn#DA#Nb#Pa	100.00
Nb#Ro#Pisa	73.00
Dresden#Pa#Ro#Pisa#Avi	235.00
Danzig#Mo#Pa#Nb#DA	149.00
sum of costs	**2379.00**

Tab. 3: Cost of routes chosen by the fuzzy routing system

route chosen by minimising the length	cost of the route
HH#Kiel2#Rost#Len#Mo	271.00
HH#Kiel#Krakau	244.00
HH#H#Nb#Ro	312.00
HH#H#Nb#Ro#Pisa#Roma	387.00

Tr#F#Pisa#Roma	136.00
Tr#DA#Mch1#Ro	361.00
Tr#DA#Nb#Pa#Athen	239.00
Bn#DA#Mch1#Ro	255.00
Bn#Tr#F#Lyon2#Avi	130.00
F#La#Mch3#Ro#Pa#Athen#Samos	194.00
F#La#Mch3#Ro#Pa#Mo#Thes2	209.00
F#La#Mch3#Ro#Pa#Mo	166.00
Bn#DA#Nb#Pa	101.00
Nb#Ro#Pisa	74.00
Dresden#Pa#Ro#Pisa#Avi	236.00
Danzig#Krakau#Dresden#A#DA	253.00
sum of costs	**3568.00**

Tab. 4: Cost of routes chosen by minimising the length

route chosen by minimising the hops	**cost of the route**
HH#Kiel#Krakau#Mo	402.00
HH#Kiel#Krakau	244.00
HH#F#Pisa#Ro	132.00
HH#F#Pisa#Roma	141.00
Tr#F#Pisa#Roma	136.00
Tr#DA#Mch1#Ro	361.00
Tr#DA#Nb#Pa#Athen	239.00
Bn#DA#Mch1#Ro	255.00
Bn#H#F#Lyon#Avi	359.00
F#HH#Kiel#Krakau#Samos	406.00
F#HH#Kiel#Krakau#Mo#Thes2	481.00
F#HH#Kiel#Krakau#Mo	438.00
Bn#DA#Nb#Pa	101.00
Nb#Ro#Pisa	74.00
Dresden#Pa#Ro#Pisa#Avi	236.00
Danzig#Mo#Pa#Nb#DA	150.00
sum of costs	**4155.00**

Tab. 5: Cost of routes chosen by minimising the hops

So the fuzzy rule base offers a way of making route choices, which minimises costs. This is a very important competitive advantage.

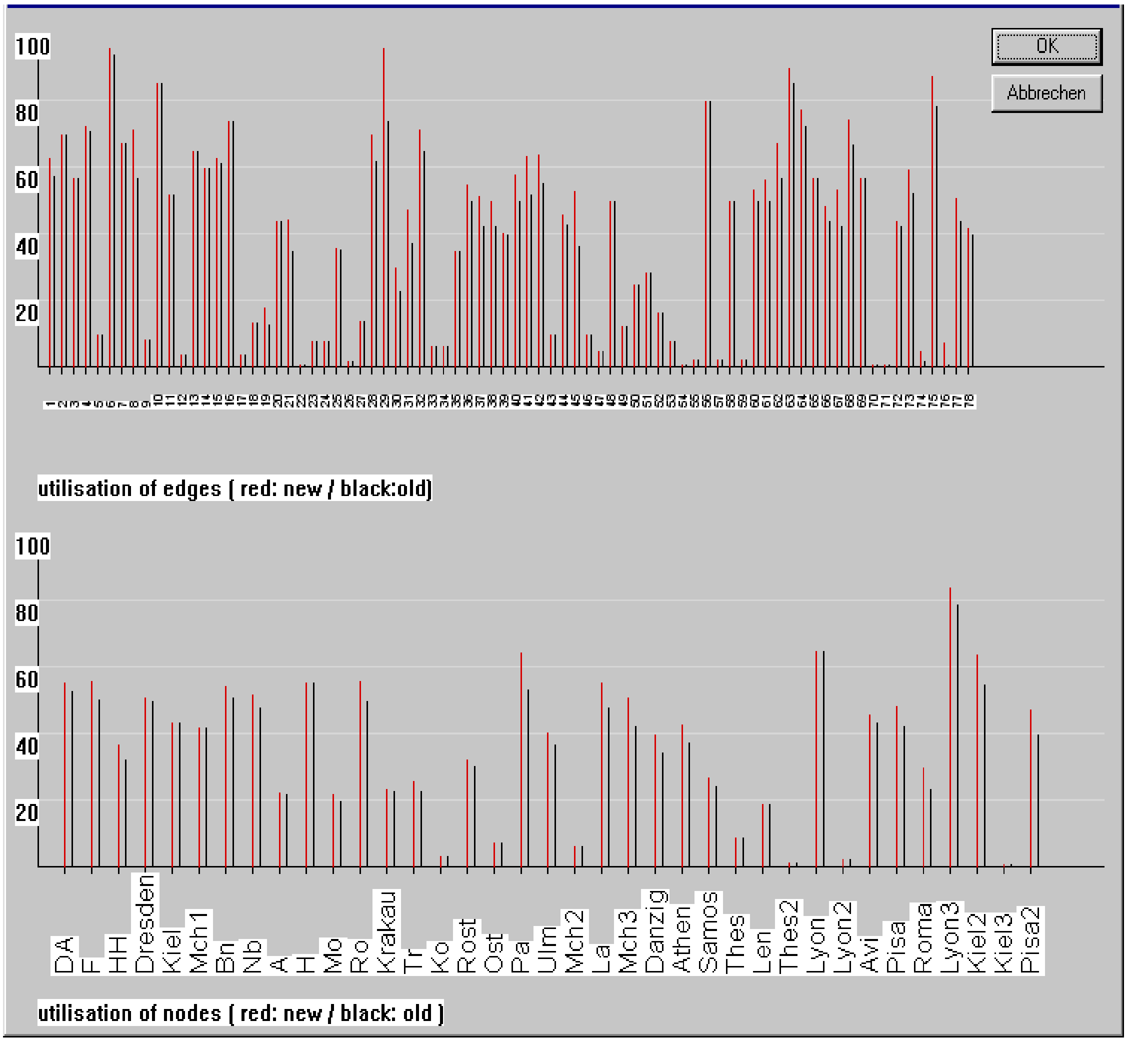

Fig. 5: Observation of utilisation

Fig. 5 shows the observation of the rate of utilisation. 500 different routes are chosen. The utilisation changes as expected when the fuzzy rules handle objects with low utilisation rates. However, some objects whose utilisation rate is greater than 80% are not handled as expected.

Edge 29, *Pa*→*Mo* is used although the utilisation rate is greater than 80%. But after looking at the data in detail, the reason is obvious: the quality and the utilisation rate of the node *Pa* and *Mo* are good in the sense of the fuzzy rules and there is no alternative edge in that graph which could be used.

The node Lyon3 is used although its utilisation rate is greater than 80%. For this example the whole path from F to Avi has to be considered (see Fig.4); this means the minimum of the sum of the edges.

6 Conclusion and further work

The method discussed above is a successful way to perform the edge weighting in a transport network. It offers a way to choose routes, so that costs are minimized and the utilisation is balanced. The fuzzy rule base can easily be adapted when technical or economical requirements change.
But this method cannot use implicit knowledge, which is available in form of “good routes”. To derive benefit out of such data, it is necessary to add learning capabilities as found in neural networks. So the fuzzy rule base is transformed into a neural network. The transformation is reversible. The reversibility is necessary to observe what the network has learned. A fuzzy rule base can be read and interpreted, so that the new information in the “trained” rule base can be checked and feedback given to the experts.
In future study, the edge weighting method performed by the fuzzy rule base will be integrated into the Dijkstra algorithm directly. A short description of this idea can be found in [4].

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Figures:

Tables: