The International Journal of
TRANSPORT & LOGISTICS
Međunarodni časopis
TRANSPORT I LOGISTIKA

UDC: 65.015.13:65.012.34

FUZZY SYSTEM FOR VEHICLE DESIGN ROUTE

FAZI SISTEM ZA PROJEKTOVANJE RUTA VOZILA

Gordana RADIVOJEVIĆ
Mihailo Pupin Institute, Belgrade, Serbia

Abstract: *Dial-A-Ride system is type of transportation in which carrier owns fleet and realize transport on relations and in time demanded by customers. Different versions of this type of transportation are present in everyday use. Solving problem of design route and scheduling in real time is dynamic case of this problem. In dynamic case, problems are being solved by dispatcher in real time. Dispatchers make decisions based on subjective evaluation of present and future situation on transport network, personal experience and intuition. Fuzzy system for design route of traffic devices for Dial-A-Ride system is described in this paper. Two different approximate reasoning algorithms are developed within fuzzy system: for choise of vehicle for realization of new request for transport and for defining route of vehicle. Developed fuzzy system has the possibility of usage in concrete conditions.*

Key words: *Dial-A-Ride, Transportation, Fuzzy Logic, Approximate Reasoning Algorithm.*

Apstrakt: *Dial-a-Ride sistem je oblik prevoza u kome prevozilac poseduje vozni park i realizuje prevoz na relacijama i u vreme kako to zahtevaju korisnici. Različite varijante ovog oblika prevoza su prisutne u svakodnevnoj praksi. Rešavanje problema projektovanja ruta i redova vožnje u realnom vremenu je dinamički slučaj ovog problema. U dinamičkom slučaju se problemi rešavaju odlučivanjem dispečera u realnom vremenu. Dispečeri donose odluke na osnovu subjektivne procene trenutne i buduće situacije na transportnoj mreži, ličnog iskustva i intuicije. U ovom radu je opisan fazi sistem za projektovanje ruta saobraćajnih sredstava za dynamic Dial-a-Ride system. U okviru fazi sistema razvijena su dva algoritma aprosimativnog rezonovanja: za izbor vozila za realizaciju novog zahteva za prevozom i za definisanje rute vozila. Razvijeni fazi sistem ima mogućnost primene u konkretnim uslovima.*

Ključne reči: *dial-a-ride, transport, fazi logika, algoritam aprosimativnog rezonovanja.*

1 INTRODUCTION

Dial-A-Ride system is type of transportation in which carrier owns car park and realize transport on relations and in time demanded by customers. Different versions of this kind of transportation are present in everyday use: transport of old and ill people, transport in areas with low density where there is no public transport, different type of transportation in city municipal services etc. Static and dynamic case can be defined while solving problems of design route and schedules. Static case considers that group of requests for

1 UVOD

Dial-a-Ride sistem je oblik prevoza u kome prevozilac poseduje vozni park i realizuje prevoz na relacijama i u vreme kako to zahtevaju korisnici. Različite varijante ovog oblika prevoza su prisutne u svakodnevnoj praksi: prevoz starih i bolesnih lica, prevoz u oblastima sa malom gustinom naseljenosti gde ne postoji javni gradski prevoz, različiti oblici prevoza u gradskim komunalnim službama, i dr. Pri rešavanju problema projektovanja ruta i redova vožnje mogu se definisati statički i dinamički slučaj. Statički slučaj podrazumeva da su skup zahteva za

transport and data of traffic resources are known in advance. Then design route and time schedules are made for future period with known parameters of transport process. Dynamic case considers solving problems of design route and scheduling of traffic resources in real time.

Considering dynamic and static character of these problems, the approaches for their solving are different as well. Basic characteristic of solving problem in static case are determination and that there is enough time for making good solutions. In dynamic case, problems are being solved by dispatcher's decisions in real time. Design route of traffic resources is mostly direct outcome of dispatcher's decision. Dispatcher makes decisions based on subjective evaluation of present and future situation on transport network, personal experience and intuition.

The aim of this work is solving problem of design route and scheduling for dynamic case of Dial-A-Ride system. In the work is shown fuzzy system for design route based on using fuzzy theory and approximate reasoning algorithms.

The work is organized as followed. In first part is described Dial-A-ride system and is given the most significant overview of literature in area of fuzzy theory and its use in traffic. Second part of the work contains postulate of problem of design route for dynamic Dial-A-Ride system. Third part describes fuzzy system for design vehicle route. Fourth part contains final analyzing.

2 TRANSPORT SYSTEM DIAL-A-RIDE

In Dial-A-ride system carrier owns car park with which he transport passengers on certain area. Transport is realized on relations and on time demanded by passengers. The basic aim of transport is servicing of group of requests for transport in certain period of time. This transport system is used for transport of passengers in areas with low density or for transport of handicapped, old and sick people in big towns. Different versions of this transport system are use in city municipal services which deals with gathering and distribution of goods and passengers.

prevozom i podaci o saobraćajnim sredstvima unapred poznati. Tada se projektovanje ruta i reda vožnje radi za neki budući period sa poznatim parametrima transportnog procesa. Dinamički slučaj podrazumeva rešavanje problema projektovanja ruta i reda vožnje saobraćajnih sredstava u realnom vremenu.

S obzirom na dinamički i statički karakter ovih problema, razlikuju se i pristupi njihovom rešavanju. Osnovne karakteristike rešavanja problema u statičkom slučaju su determinističnost i postojanje dovoljno vremena za dobijanje kvalitetnih rešenja. U dinamičkom slučaju se problemi rešavaju odlučivanjem dispečera u realnom vremenu. Projektovanje ruta saobraćajnih sredstava je uglavnom direktna posledica dispečerske odluke. Dispečeri donose odluke na osnovu subjektivne procene trenutne i buduće situacije na transportnoj mreži, ličnog iskustva i intuicije.

Cilj ovoga rada je rešavanje problema projektovanja ruta i redova vožnje za dinamički slučaj Dial-a-Ride sistema. U radu je prikazan fazi sistem za projektovanje ruta, koji se zasniva na primeni fazi teorije i algoritama aproksimativnog rezonovanja.

Rad je organizovan na sledeći način. U prvom delu je opisan Dial-a-Ride sistem i dat je najznačajniji pregled literature u oblasti fazi teorije i njene primene u saobraćaju. Drugi deo rada obuhvata postavku problema projektovanja ruta za dinamički Dial-a-Ride sistem. U trećem delu je opisan fazi sistem za projektovanje ruta vozila. Četvrti deo obuhvata zaključna razmatranja.

2 TRANSPORTNI SISTEM NAZOVI VOŽNJU

U Dial-a-ride sistemu prevozilac poseduje vozni park, kojim obavlja prevoz putnika na određenom području. Prevoz se realizuje na relacijama i u vreme kako to zahtevaju putnici. Osnovni cilj prevozioca je opsluživanje skupa zahteva za prevozom u određenom periodu. Ovaj transportni sistem se primenjuje za prevoz putnika u oblastima sa malom gustinom naseljenosti ili za prevoz hendikepiranih, starih i bolesnih lica u velikim gradovima. Različite varijante ovog sistema prevoza se primenjuju u gradskim komunalnim službama, koje se bave prikupljanjem i distribucijom robe ili putnika.

Gathering of requests for transport is realized in dispatcher center. Each request for transport is described with stating and finishing point of movement and desired time of start of service. Maximization of number of services requests, minimization of transport distance, minimization of number of required vehicles, minimization of empty rides, etc. can be the aim of carrier when design route and scheduling. Criteria for design route can be various and depend on work organization and carrier business politics.

Dial-A-Ride system has static and dynamic case. Static case is when requests for transport are gathering today for tomorrow. Design route and scheduling for the next day are made on the behavior of previous working day. Dynamic case is when design route and scheduling are made in real time. User calls dispatcher center and makes a request for transport. Dispatcher makes immediate decision on request realization based on vehicles schedules and conditions on transport network, or the request is dropped if all the vehicles are busy.

Previous studies in this area consider great number of papers dealing with design route and scheduling of traffic resources. Bodin and Golden (1981) give classification of problem of design route and scheduling of traffic resources based on basic characteristics of transport process: service time, number of depots on network, size and structure of car park, capacity of vehicle resources, limitations in system, etc. There are different versions for transport system Dial-A-Ride in previous studies: one or more depots of fleet, one or more vehicles in fleet, homogeneous or heterogeneous fleet, existing of time intervals or time moments that describe time of service beginning or finishing, static or dynamic case, etc. Stein (1978) and Psaraftis (1980, 1983) have studied transport systems Dial-A-Ride in which there are no time windows and one vehicle service. Sexton and Bodin (1985) dealed with static case of transport system Dial-A-Ride with defined time intervals and larger number of vehicles servicing the users. In their work, Solomon and Desrosiers (1988) give overview of various problems in design route and scheduling of traffic resources with existing time intervals.

Prikupljanje zahteva za prevozom se realizuje u dispečerskom centru. Svaki zahtev za prevozom je opisan izvorom i ciljem kretanja i željenim vremenom početka opsluge. Pri projektovanju ruta i reda vožnje, cilj prevozioca može biti maksimizacija broja opsluženih zahteva, minimizacija rastojanja prevoza, minimizacija broja potrebnih vozila, minimizacija praznih vožnji, i dr. Kriterijumi projektovanja ruta mogu biti različiti i zavise od organizacije rada i poslovne politike prevozioca.

Dial-a-ride sistem ima statički i dinamički slučaj. Statički slučaj je kada se zahtevi za prevozom prikupljaju danas za sutra. Na kraju radnog dana se radi projektovanje ruta i reda vožnje za sledeći dan. Dinamički slučaj je kada se projektovanje ruta i reda vožnje radi u realnom vremenu. Korisnik se javlja dispečerskom centru i prijavljuje zahtev za prevozom. Dispečer odmah donosi odluku o realizaciji zahteva, na osnovu rasporeda i stanja vozila na transportnoj mreži, ili zahtev dobija otkaz, ako su sva vozila zauzeta.

Dosadašnja istraživanja u ovoj oblasti obuhvataju veliki broj radova koji se bave projektovanjem ruta i redova vožnje saobraćajnih sredstava. Bodin i Golden (1981) daju klasifikaciju problema projektovanja ruta i reda vožnje saobraćajnih sredstava, prema osnovnim karakteristikama prevoznog procesa: vreme opsluge, broj depoa na mreži, veličina i struktura voznog parka, kapacitet saobraćajnih sredstava, ograničenja u sistemu, i dr. U dosadašnjim istraživanjima postoje različite varijante za transportni sistem "Nazovi vožnju": jedan ili više depoa voznog parka, jedno ili više vozila u voznom parku, homogen ili heterogen vozni park, postojanje vremenskih intervala ili vremenskih momenata koji opisuju vreme početka ili završetka opsluge, statički ili dinamički slučaj, itd. Stein (1978) i Psaraftis (1980, 1983) su izučavali transportne sisteme "Nazovi vožnju" u kojima ne postoje vremenski intervali i kada opslugu obavlja samo jedno saobraćajno sredstvo. Sexton i Bodin (1985) su se bavili statičkim slučajem transportnog sistema "Nazovi vožnju" sa odredjenim vremenskim intervalima i većim brojem vozila, koja opslužuju korisnike. Solomon i Desrosiers (1988) u svom radu daju pregled različitih problema projektovanja ruta i reda vožnje saobraćajnih sredstava sa postojanjem vremenskih intervala.

Development of fuzzy logic and use of fuzzy systems in manipulation of processes have consequence in use of fuzzy theory in traffic and transport. In their book, Teodorović and Kikuchi (1991, 1994) describe use of fuzzy theory in traffic. Kikuchi and Donnely (1992), Teodorović and Pavković (1992), Vukadinović and Teodorović (1994), Teodorović and Radivojević (1997) also researched use of fuzzy theory in solving problems of design route and scheduling.

3 STATEMENT OF THE PROBLEM

In this work, the dynamic Dial-A-Ride system will be examined, where design route is made in real time. Carrier owns fleet and realizes transport in certain area, on relations and in time demanded by customers. Dispatcher center is equipped with multi-line switching office (center) and radio-station. User can request transport to dispatcher center of carrier by phone, maximum t* minutes (i.e. 30 minutes) before desired start of transport. After noticing the request, dispatcher must immediately make decision about realization of request, telling the user number of vehicle which will make the transport or the user is being dismissed if all the vehicles are busy. Vehicles are equipped with radio-stations, so that they are in non-stop connection with dispatcher center during work day.

During work day, dispatcher center gathers requests for transport nonstop, and is immediately giving them to specified vehicles to realize. Based on present location of each vehicle on the network and previously assigned requests, dispatcher decides to which vehicle will be assigned for transport. Request for transport given to one vehicle, cannot be shifted to some other vehicle to realize. Vehicle which has do new ride, goes from present location to location which is beginning of new request immediately after receiving information. There can be more passengers in vehicle at the same time. Dispatcher decides sentence of exiting of passengers, apropos defining route of vehicle. Giving first transport request, specified vehicle starts its route, which in first step considers beginning and the end of first request. When the vehicle is given second request, its route is expanding, and sentence of exiting of passengers is being decided by dispatcher.

Razvoj fazi logike i primena fazi sistema u upravljanju procesima imali su za posledicu primenu fazi teorije u saobraćaju i transportu. Teodorović i Kikuchi (1991, 1994) u svojoj knjizi opisuju primenu fazi teorije u saobraćaju. Primenom fazi teorije u rešavanju problema projektovanja ruta i reda vožnje bavili su se Kikuchi i Donnely (1992), Teodorović i Pavković (1992), Vukadinović i Teodorović (1994), Teodorović i Radivojević (1997, 2000).

3 POSTAVKA PROBLEMA

U ovom radu će biti razmatran the dynamic Dial-A-Ride system, kod koga se projektovanje ruta vozila radi u realnom vremenu. Prevozilac poseduje vozni park, kojim obavlja prevoz na određenoj teritoriji, na relacijama i u vreme kako zahtevaju korisnici. Dispečerski centar prevozioca je opremljen telefonskom centralom sa više linija i radio-stanicom. Korisnici mogu da telefonski prijave svoj zahtev za prevozom dispečerskom centru prevozioca, najkasnije t* minuta (npr. 30 minuta) pre željenog vremena početka prevoza. Dispečer odmah po evidentiranju zahteva mora da donose odluku o realizaciji zahteva, saopštavajući korisniku broj vozila koje će obaviti prevoz ili korisnik dobija otkaz ako su sva vozila zauzeta. Vozila su opremljena radio-stanicama, tako da su u toku radnog dana u neprekidnoj vezi sa dispečerskim centrom.

U toku radnog dana dispečerski centar neprekidno prikuplja zahteve za prevozom i odmah ih dodeljuje određenim vozilima na realizaciju. Dispečer na osnovu trenutne lokacije svakog vozila na mreži i prethodno dodeljenih zahteva, određuje kom vozilu će dodeliti novi zahtev za prevozom. Zahtev za prevozom, koji je dodeljen jednom vozilu, ne može se kasnije dodeliti nekom drugom vozilu na realizaciju. Vozilo, koje treba da obavi novu vožnju, odmah po prijemu informacije odlazi iz trenutne lokacije u lokaciju, koja je početak novog zahteva. U vozilu se istovremeno može naći više putnika. Redosled izlaza putnika iz vozila, odnosno, definisanje rute vozila, određuje dispečer. Dodeljivanjem prvog zahteva za prevozom, određeno vozilo započinje svoju rutu, koja u prvom koraku obuhvata početak i kraj prvog zahteva. Kada se ovom vozilu dodeli drugi zahtev, njegova ruta se proširuje, a redosled izlaza putnika iz vozila definiše dispečer.

Realization of transport requests is made on certain transport network. Transport network is city area, which consists of group of nodes – city junctures and group of streets connecting these junctions (nodes). Basic characteristics of transport network are:

- M - number of nodes on the network,
- X_p, Y_p - coordinates of node p on the network,
- D_{pq} - distance between nodes p and q,
- TT_{pq} - travel time between nodes p and q.

Carrier owns homogenous fleet with one depot on transport network. Vehicles are minibuses, which provide simultaneous transport of many passengers. On the beginning of work, all the vehicles are in the depot. Vehicle exits the depot when is assigned for the first transport request. If during the drive vehicle gets new request, it goes to accomplish it ... Vehicle returns to the depot when the last passenger exits the vehicle, it means when it realized all assigned transport requests. Vehicles don't have limited time shift, but work during whole day. Characteristics of car park are:

- N - number of vehicles,
- NC - capacity of vehicles,
- TC - coefficient of maximum increase of travel time,
- D - depot location on transport network.

Coefficient of maximum increase of travel time TC is defined by carrier's business politics. It is the measure of quality of realized transport services, because it limits the time which each passenger can be in the vehicle. On figure 1 is shown transport network on which the transport is being realized.

Transport of one passenger on specified relation in specified time is considered as transport request. On figure 2 is shown transport request *i*.

Realizacija zahteva za prevozom se obavlja na određenoj transportnoj mreži. Transportna mreža je gradsko područje, koje sastoji od skupa čvorova - gradskih raskrsnica, i skupa ulica, koje povezuju te čvorove. Osnovne karakteristike transportne mreže su:

- M - broj čvorova na mreži,
- X_p, Y_p - koordinate čvora p na mreži,
- D_{pq} - rastojanje između čvorova p i q,
- TT_{pq} - vreme putovanja između čvorova p i q.

Prevozilac poseduje homogen vozni park sa jednim depoom na transportnoj mreži. Vozila su mini busevi, koji obezbeđuju istovremeni prevoz više putnika. Na početku rada sva vozila se nalaze u depou. Vozilo izlazi iz depoa kada dobije prvi zahtev za prevozom. Ako u toku vožnje vozilo dobije novi zahtev, odlazi da primi njega, ... Vozilo se vraća u depo kada poslednji putnik izađe iz vozila tj. kada je realizovalo sve dodeljene zahteve za prevozom. Vozila nemaju ograničenje trajanja radnog vremena već rade u toku celog dana. Karakteristike voznog parka su:

- N - broj vozila,
- NC - kapacitet vozila,
- TC - koeficijent maksimalnog povećanja vremena putovanja,
- D - lokacija depoa na transportnoj mreži.

Koeficijent maksimalnog povećanja vremena putovanja TC je određen poslovnom politikom prevozioca. To je mera kvaliteta ostvarenih prevoznih usluga, jer se na ovaj način ograničava vreme koje svaki putnik može provesti u vozilu. Na slici 1 je prikazana transportna mreža na kojoj se realizuje prevoz.

Pod zahtevom za prevozom se podrazumeva prevoz jednog putnika na određenoj relaciji u određeno vreme. Na slici 2 je prikazan zahtev za prevozom i.

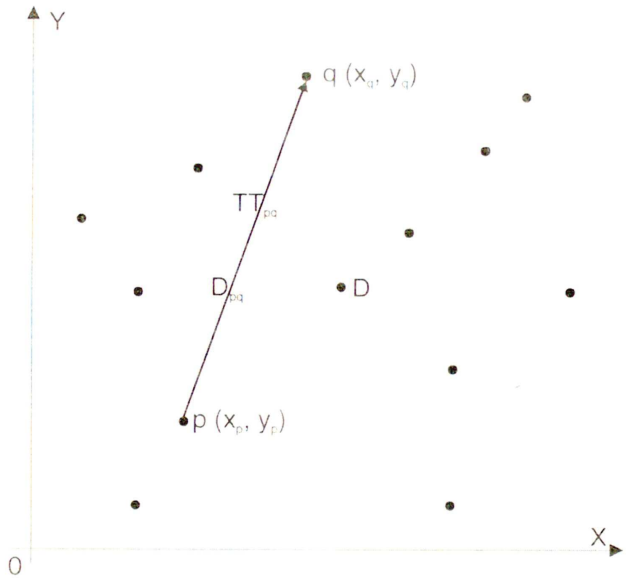

Figure 1 Transportna mreža na kojoj se realizuje prevoz putnika
slika 1 Transportna mreža na kojoj se realizuje prevoz putnika

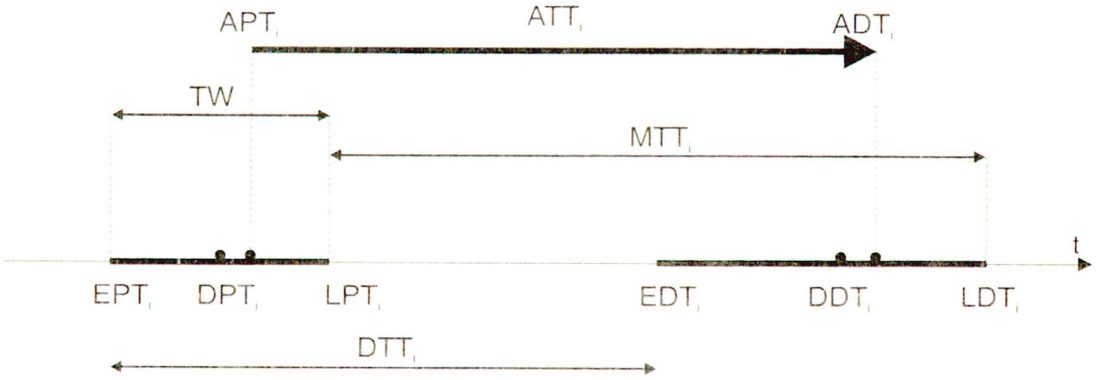

Figure 2 Characteristics of transport request i
slika 2 Karakteristike zahteva za prevozom i

Characteristics of transport request are:

i^+ - i-th passenger's origin,
i-th - passenger's destination,
DPT_i - desired pick-up time of the i-th passenger,
EPT_i - earliest pick-up time of the i-th passenger,
LPT_i - latest pick-up time of the i-th passenger,
APT_i - actual pick-up time of the i-th passenger,
DDT_i - desired drop-off time of the i-th passenger,
EDT_i - earliest drop-off time of the i-th passenger,
LDT_i - latest drop-off time of the i-th passenger,
ADT_i - actual drop-off time of the i-th passenger,
DTT_i - direct travel time of the i-th passenger,
MTT_i - maximum travel time of the i-th passenger,
ATT_i - actual time of the i-th passenger,
TW - time window in which request' service must start.

When user makes the transport request in moment TP_i, he defines transport relation (i^+, i^-) and desired pick-up time. Based on TW carrier determines earliest (EPT_i) and latest (LPT_i) pick-up time. Difference between earliest pick-up time and time of request must be greater or equal the time needed for direct ride from depot to node of passenger's origin:

$$EPT_i - TP_i \geq TT_{Di} \quad (1)$$

where TT_{Di} is time needed for direct ride from depot D to node of passenger's origin i^+. This condition provides that new transport time cannot be dismissed cause the vehicle can't reach from depot to node i^+ by earliest pick-up time.

Based on data given by user, carrier defines all the other characteristic of travel request. Direct Travel Time (DTT_i) is time of traveling between nodes i^+ and i^-. Maximum travel time is defined by relation:

$$MTT_i = TC \cdot DTT_i \quad (2)$$

Time moment of earliest and latest drop-off time are defined by relations::

$$EDT_i = EPT_i + DTT_i \quad (3)$$

$$LDT_i = LPT_i + MTT_i \quad (4)$$

Actual pick-up time (APT_i) and actual drop-off time (ADT_i) of request realization (i) are definined in moment from deciding which vehicle will service the request and sentence of exiting of passengers from vehicle. Relations for actual moments of pick-up and drop-off time of request realization must be:

$$EPT_i \leq APT_i \leq LPT_i \quad (5)$$

$$EDT_i \leq ADT_i \leq LDT_i \quad (6)$$

It means pick-up and drop-off time must be within time defined intervals. ATT_i represents actual time for realization of request and the relation is:

$$DTT_i \leq ATT_i \leq MTT_i \quad (7)$$

Kada korisnik prijavljuje prevoziocu zahtev za prevozom u trenutku TP_i, on definiše relaciju prevoza (i^+, i^-) i željeno vreme početka opsluge zahteva. Na osnovu TW prevozilac određuje najranije (EPT_i) i najkasnije vreme (LPT_i) početka opsluge. Razlika između najranijeg momenta početka opsluge i momenta prijave zahteva mora biti veća ili jednaka vremenu trajanja direktne vožnje od depoa do čvora početka zahteva:

$$EPT_i - TP_i \geq TT_{Di} \quad (1)$$

gde TT_{Di} vreme trajanja direktne vožnje od depoa D do čvora početka opsluge i^+. Ovim uslovom se obezbeđuje da novi zahtev za prevozom ne može dobiti otkaz jer vozilo ne može da stigne iz depoa u čvor i^+ do najranijeg momenta početka realizacije zahteva.

Na osnovu podataka, koje zadaje korisnik, prevozilac definiše ostale karakteristike zahteva za prevozom. Vreme direktnog putovanja (DTT_i) je vreme putovanja između čvorova i^+ i i^-. Maksimalno vreme putovanja se određuje prema relaciji:

$$MTT_i = TC \cdot DTT_i \quad (2)$$

Vremenski momenti najranijeg i najkasnijeg završetka realizacije zahteva se određuju preko relacija:

$$EDT_i = EPT_i + DTT_i \quad (3)$$

$$LDT_i = LPT_i + MTT_i \quad (4)$$

Stvarni momenti početka (APT_i) i završetka (ADT_i) realizacije zahteva (i) se određuju u trenutku donošenja odluka o vozilu koje će realizovati zahtev i redosledu izlaza putnika iz vozila. Za stvarne momente početka i završetka realizacije zahteva moraju da važe relacije:

$$EPT_i \leq APT_i \leq LPT_i \quad (5)$$

$$EDT_i \leq ADT_i \leq LDT_i \quad (6)$$

tj. vreme početka i završetka zahteva mora biti u definisanim vremenskim intervalima. ATT_i predstavlja stvarno vreme trajanja realizacije zahteva i važi relacija:

$$DTT_i \leq ATT_i \leq MTT_i \quad (7)$$

Ratio between actual time of request realization (ATT_i) and direct travel time on that relation (DTT_i) is always minor or equal to coefficient TC and represents quality value of accomplished transport services by carrier.

4 FUZZY SYSTEM

For solving problem of design route and scheduling for the dynamic Dial-A-Ride system, this work developed fuzzy system based on use of fuzzy logic. Two approximate reasoning algorithms are developed within fuzzy system, which provide making decision on realization of transport request in real time. The dynamic Dial-A-Ride system represents the system in which user makes phone calls and generate the transport request. Dispatcher decision making is in real time and immediately after receiving the request dispatcher must make decision on which vehicle will realize the request and a new route of the vehicle. With first approximate reasoning algorithm comes decision on which vehicle will realize new transport request. Second approximate reasoning algorithm decides new route of vehicle, after adding new transport request.

In everyday's tasks, while deterring travel time between two nodes on the network, dispatchers never use phrases like "*time travel is 13 minutes and 22 seconds*". Considering the existence of uncertainty indefiniteness in executing transport process, it is not possible to precisely determine travel time on transport network. The most common phrases used are approximation of numeric value ("*travel time is around 13 minutes*") or linguistic form ("*travel time is short*"). Dispatcher's evaluation is based on experience and subjective evaluation of time travel. That's why in this work time travels on transport network and time moments, which describe transport request, describe with fuzzy numbers. Based on approximate values and linguistic forms, all time characteristic can be shown by fuzzy numbers. For example, desired pick-up time is DPT_i, earliest pick-up time and latest pick-up time are EPT_i and LPT_i. In developed fuzzy system, desired time of pick-up time DPT_i is presented by triangle fuzzy number where earliest and latest pick-up time represents interval of fuzzy group trust – left and right limit of fuzzy number. Desired time of pick-up time of

Odnos između stvarnog trajanja realizacije zahteva (ATT_i) i vremena direktne vožnje na toj relaciji (DTT_i) uvek je manji ili jednak koeficijentu TC i predstavlja meru kvaliteta ostvarenih prevoznih usluga prevozioca.

4 FUZZY SYSTEM

U ovom radu je za rešavanje problema projektovanja ruta i reda vožnje saobraćajnih sredstava za the dynamic Dial-A-Ride system razvijen fazi sistem, koji se zasniva na primeni fazi logike. U okviru fazi sistema su razvijena dva algoritma aproksimativnog rezonovanja, koji u realnom vremenu obezbeđuju donošenje odluke o realizaciji zahteva za prevozom. The dynamic Dial-A-Ride system predstavlja sistem u kome se korisnici telefonom javljaju i prijavljuju svoj zahtev za prevozom. Odlučivanje dispečera je u realnom vremenu i odmah po prijemu zahteva dispečer mora da donese odluku o vozilu koje će realizovati zahtev i o novoj ruti tog vozila. Prvim algoritmom aproksimativnog rezonovanja se dolazi do odluke o vozilu koje će realizovati novi zahtev za prevozom. Drugi algoritam aproksimativnog rezonovanja određuje novu rutu vozila, posle dodavanja novog zahteva za prevozom.

U svakodnevnom radu dispečeri, pri određivanju vremena putovanja između dva čvora na mreži, nikada ne koriste fraze oblika: "vreme putovanja iznosi 13 minuta i 22 sekunde". S obzirom na postojanje neizvesnosti i neodređenosti u izvršavanju prevoznog procesa, nije moguće precizno definisanje vremena trajanja putovanja na transportnoj mreži. Najčešći oblici izražavanja dispečera su aproksimacija numeričke vrednosti ("vreme putovanja je oko 13 minuta") ili lingvistička forma ("vreme putovanja je malo"). Procena dispečera se zasniva na iskustvu i subjektivnoj oceni vremena putovanja. Zbog toga se u ovom radu vremena putovanja na transportnoj mreži i vremenski momenti, koji opisuju zahtev za prevozom, opisuju fazi brojevima. Na osnovu aproksimativnih vrednosti i lingvističkih formi, sve vremenske karakteristike se mogu predstaviti fazi brojevima. Na primer, željeno vreme korisnika za početak opsluge zahteva je DPT_i, a najraniji i najkasniji trenutak početka opsluge su EPT_i i LPT_i. U razvijenom fazi sistemu se željeno vreme početka opsluge DPT_i predstavlja trouglastim fazi brojem gde najraniji i najkasniji trenutak početka opsluge zahteva predstavljaju interval poverenja fazi skupa tj. levu i desnu granicu fazi broja. Željeno vreme

request realization DPT_i is a value with the highest importance because customer has "biggest wish" that pick-up time of request realization is in that moment.

In the moment of receiving new transport request, dispatcher knows the position of all the vehicles on transport network and characteristics of new request. "Vehicle position" considers planned route, present location of each vehicle and time when the vehicle is on present location. On figure 3 is shown the vehicle position on the network when receiving new request *i*.

početka realizacije zahteva DPT_i je vrednost sa najvećim stepenom pripadnosti jer korisnik ima "najveću želju" da početak realizacije zahteva bude u tom trenutku.

U trenutku prijave novog zahteva za prevozom dispečer zna raspored svih vozila na transportnoj mreži i karakteristike novog zahteva. Pod rasporedom vozila se podrazumeva planirana ruta, trenutna pozicija svakog vozila i vreme kada se vozilo nalazi na trenutnoj poziciji. Na slici 3 je prikazan raspored vozila na mreži u trenutku prijave novog zahteva *i*.

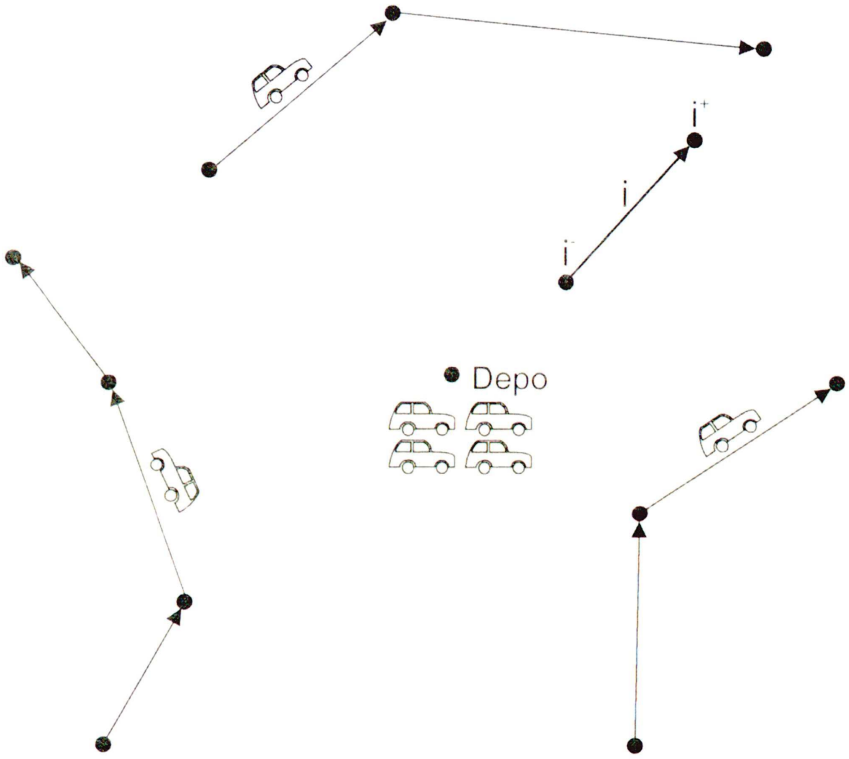

Figure 3 Position on the network when receiving new request i
slika 3 Raspored vozila na transportnoj mreži u trenutku prijave zahteva za prevozom i

When new transport request is received, dispatcher makes decision which vehicle will realize it and on new route of that vehicle. When making decision, dispatcher can use various tactics, which depend on carrier business politics or on present situation on transport network. When dispatcher makes a decision, his thinking looks like: *if ... then ...* Criteria which determine dispatcher's decision can be various: number of available vehicles on network, present use of vehicles, distance of vehicle from pick-up place of new request, time which the vehicle would wait for start of realization of new request...etc.

Kada se prijavi novi zahtev za prevozom dispečer donosi odluku o vozilu koje će ga realizovati i o novoj ruti tog vozila. U donošenju odluke dispečer se može rukovoditi različitim taktikama, koje zavise od poslovne politike prevozioca ili trenutne situacije na transportnoj mreži. Kada dispečer donosi neku odluku njegovo razmišljanje je oblika: *if ... then ...* Kriterijumi, koji opredeljuju dispečera da donese neku odluku, mogu biti različiti: broj raspoloživih vozila na mreži, trenutno angažovanje vozila, udaljenost vozila od mesta početka novog zahteva, vreme koje bi vozilo čekalo na početak realizacije novog zahteva, ... itd.

Dispatcher's decision making can hardly be described with some exact mathematic model, which will provide decision making in various situations. When dispatchers describe made decisions, they rather use qualitative than quantitative phrases. Experience and "intuition" are in the basis of dispatcher's decision making in certain situation. Qualitative or fuzzy nature of human way of thinking leads to use of fuzzy logic systems, which can be modeled on experience and behaviour of dispatcher when making a decision. Approximate reasoning algorithms are group of rules which describe dispatcher's behaviour in various situation of decision making. One rule describes system of dispatcher's way of thinking like: *if ... then ...* It is necessary to determine criteria for defining group of rules based on which a decision is made.

Modeling of dispatcher's reasoning can be done based on one, two, three or more criteria. Criteria of deciding can have different described values: small, medium, big. Based on experience, dispatchers concludes whether present distance of vehicle from pick-up place is short, medium, or long, and whether vehicle's time waiting for new request realization is short, medium or long. Dispatcher makes decision with certain preference. Dispatcher's preference can be described as „strong of will" to make a certain decision. Dispatcher's preference for a decision can be very weak, weak, medium, strong or very strong. Dispatcher's reasoning looks like this: *if the distance of vehicle is short and time waiting is medium, then the preference is strong*. Group of rules provides making decisions in various situations of system.

Fuzzy system for design route in transport system Dial-A-Ride considers following steps:

Step 1: Prepare of set of input values
Step 2: Choice of vehicle for realization of new request
Step 3: Design new vehicle route
Step 4: Calculation of working indices

Step 1: Prepare of set of input values
Group of input values considers data on transport network, data on new transport request and data on car park. Data on transport network are number of nodes on network and distance and travel time between all pairs of nodes.

Odlučivanje dispečera se veoma teško može opisati nekim egzaktnim matematičkim modelom, koji bi obezbedio donošenje odluka u različitim situacijama. Pri opisivanju donetih odluka dispečeri više koriste kvalitativne izraze od kvantitativnih. U osnovi dispečerskog zaključivanja je iskustvo i "osećaj" za odluku u određenoj situaciji. Kvalitativna, odnosno, fazi priroda ljudskog načina rasuđivanja upućuje na primenu fazi logičkih sistema, kojima je moguće modelirati iskustvo i ponašanje dispečera pri odlučivanju. Algoritmi aproksimativnog rezonovanja predstavljaju skup pravila, kojima se opisuje ponašanje dispečera u različitim situacijama odlučivanja. Jedno pravilo opisuje sistem dispečerskog rasuđivanja obilika: *if ... then ...* Za definisanje skupa pravila potrebno je odrediti kriterijume, na osnovu kojih se donosi neka odluka.

Modeliranje dispečerskog rasuđivanja se može uraditi na osnovu jednog, dva, tri ili više kriterijuma. Kriterijumi odlučivanja mogu imati različite opisne vrednosti: malo, srednje, veliko. Dispečer na osnovu iskustva zaključuje da je udaljenost trenutne pozicije vozila od početka novog zahteva mala, srednja ili velika, i da je vreme čekanja vozila na početak realizacije zahteva malo, srednje ili veliko. Dispečer sa određenom preferencijom donosi odluku. Preferenecija dispečera se može opisati kao "jačina želje" da se donese određena odluka. Preferencija dispečera za neku odluku može biti veoma slaba, slaba, srednja, jaka ili veoma jaka. Rasuđivanje dispečera je oblika: *ako je udaljenost vozila mala i vreme čekanja vozila srednje tada je preferencija jaka.* Skup pravila obezbeđuje odlučivanje u različitim situacijama sistema.

Fazi sistem za projektovanje ruta vozila u transportnom sistemu "Nazovi vožnju" obuhvata sledeće korake:

Step 1: Priprema skupa ulaznih veličina
Step 2: Izbor vozila za realizaciju novog zahteva za prevozom
Step 3: Projektovanje nove rute vozila
Step 4: Izračunavanje pokazatelja rada

Step 1: Priprema skupa ulaznih veličina
Skup ulaznih veličina obuhvata podatke o transportnoj mreži, podatke o novom zahtevu za prevozom i podatke o voznom parku. Podaci o transportnoj mreži su broj čvorova na mreži i rastojanje i vreme putovanja između svih parova čvorova.

Customers, who makes new request, define transport relation and desired pick-up time. The earliest and the latest drop-off time of new request are based on that.

Data on car park are number of available vehicles, location of vehicles on network and route of each vehicle with previously given transport request. When new transport request is received, it is necessary to update condition of all vehicles, so that present location, time of present location and planned route are known for each vehicle. Dispatcher must choose the vehicles which are potential candidates for realization of new request according to characteristic of new transport request and location of vehicle on the network. Choise of vehicle is being done obeying these rules:

- Giving new request to vehicle must me within allowed capacity of vehicle (NC passengers).
- Vehicle must begin realization of new request in given time interval ($EDT_j \leq ADT_j \leq LDT_j$).
- Increasing of time travel, based on input and output new request from vehicles, must not influence on request's time limits, previously given to vehicle.

This results with smaller group of available vehicles which can realize new request. When choosing vehicle, dispatcher uses the rules that vehicles that are already on the transport network should be aquired. If those vehicles cannot realize new request, than the vehicle from the depot is called. In this work, group of available vehicles is divided in three groups:

- First group – vehicles that already have requests and in the moment of receiving of new request are on the transport network
- Second group – vehicles which realized given requests and in the moment of receiving of new request are in the depot
- Third group – vehicles that had no given requests and ih the moment of receiving of new request are in the depot.

When choosing vehicles, the advantage have vehicles from the first, then the second and then the third group. This allows one vehicle to realize larger number of requests.

Korisnik, koji prijavljuje novi zahtev, zadaje relaciju prevoza i željeni vremenski interval početka opsluge. Na osnovu toga se definiše najranije i najkasnije vreme završetka opsluge novog zahteva.

Podaci o voznom parku su broj raspoloživih vozila, raspored vozila na mreži i ruta svakog vozila sa prethodno dodeljenim zahtevima za prevozom. Kada se prijavi novi zahtev za prevozom neophodno je izvršiti ažuriranje stanja svih vozila, tako je za svako vozilo poznata trenutna lokacija, vreme trenutne lokacije i planirana ruta vozila. Prema karakteristikama novog zahteva za prevozom i poziciji vozila na mreži, treba izvršiti izbor vozila, koja su potencijalni kandidati za realizaciju novog zahteva. Izbor vozila se radi uz poštovanje sledećih ograničenja:

- Dodeljivanje novog zahteva vozilu mora biti u okviru dozvoljenog kapaciteta vozila (NC putnika).
- Vozilo mora početi realizaciju novog zahteva u zadatom vremenskom intervalu ($EDT_j \leq ADT_j \leq LDT_j$).
- Povećanje vremena putovanja, koje nastaje ulazom i izlazom novog zahteva iz vozila, ne sme da utiče na vremenska ograničenja zahteva, koji su ranije dodeljeni vozilu.

Ovime se dobija manji skup raspoloživih vozila, koja mogu realizovati novi zahtev. Pri izboru vozila dispečer koristi pravilo da treba prvenstveno angažovati vozila, koja već rade na transportnoj mreži. Ako ta vozila ne mogu da realizuju novi zahtev, poziva se vozilo iz depoa. U ovom radu skup raspoloživih vozila deli se u tri grupe:

- Prva grupa - vozila koja imaju dodeljene zahteve i u trenutku prijave novog zahteva se nalaze na transportnoj mreži.
- Druga grupa - vozila koja su realizovala dodeljene zahteve i u trenutku prijave novog zahteva se nalaze u depou.
- Treća grupa - vozila koja nisu imala dodeljenih zahteva i u trenutku prijave novog zahteva se nalaze u depou.

Pri izboru vozila prednost se daje vozilima iz prve grupe, zatim iz druge i treće grupe. Ovime se obezbeđuje da se jednim vozilom realizuje što veći broj zahteva.

Step 2: Choice of vehicle for realization of new request

In this work, Choice of vehicle for realization of new transport request is made with use of fuzzy logic. The approximate reasoning algorithm for vehicle choosing is developed which allows making good decision by group of rules. Criteria for choosing vehicle for realization of new request are:

- Distance from present location to node of origin of new request, and
- Vehicle's waiting time for start of realization of new request.

Distance from actual position of vehicle to the spot of start of new request can be described by fuzzy groups "short distance", "medium distance" or "long distance". The same way, vehicle's waiting time for start of realization of request is described by fuzzy sets "short waiting", "medium waiting" and "long waiting".

Preference intension of decision maker can be shown by preference index PI whose value is from 0 to 1. When the value of preference index is 1, decision maker is sure that he will pick up that vehicle. With decrease of preference index, the will of decision maker for choosing the vehicle also decreases. Preference of decision maker can be very weak, weak, medium, strong and very strong. These levels of preference can be shown by adequate fuzzy sets.

Approximate reasoning algorithm for choosing of vehicle consists of 9 rules:

Rule 1:
If the distance is SHORT and waiting is SHORT
Then the preference is VERY STRONG
Rule 2:
If the distance is SHORT and waiting is MEDIUM
Then the preference is STRONG
Rule 3:
If the distance is SHORT and the waiting is LONG
Then the preference is MEDIUM
Rule 4:
If the distance is MEDIUM and the waiting is SHORT
Then the preference is MEDIUM

Step 2:Izbor vozila za realizaciju novog zahteva za prevozom

Izbor vozila za realizaciju novog zahteva za prevozom izvršen je u ovom radu primenom fazi logike. Razvijen je algoritam aproksimativnog rezonovanja za izbor vozila, koji skupom pravila omogućava donošenje kvalitetne odluke. Pri izboru vozila cilj je da se minimizira dodatna vožnja i čekanje vozila. Kriterijumi izbora vozila za realizaciju novog zahteva za prevozom su:

- Rastojanje od trenutne pozicije vozila do čvora početka novog zahteva, i
- Vreme čekanja vozila na početak realizacije novog zahteva.

Rastojanje od trenutne pozicije vozila do mesta početka novog zahteva može se opisati fazi skupovima "malo rastojanje", "srednje rastojanje" ili "veliko rastojanje". Na isti način, vreme čekanja vozila na početak realizacije zahteva opisuje se fazi skupovima "malo čekanje", "srednje čekanje" i "veliko čekanje".

Jačina preferencije donosioca odluke može biti iskazana indeksom preferencije PI čija je vrednost od 0 do 1. Kada je vrednost indeksa preferencije 1 donosilac odluke je siguran da će izabrati to vozilo. Sa opadanjem indeksa preferencije opada i jačina želje donosioca odluke za izborom vozila. Preferencija donosioca odluke može biti: veoma slaba, slaba, srednja, jaka i veoma jaka. Ovi nivoi preferencije se mogu prikazati odgovarajućim fazi skupovima.

Algoritam aproksimativnog rezonovanja za izbor vozila se sastoji od sledećih 9 pravila:

Pravilo 1:
Ako je rastojanje MALO i čekanje MALO
Tada je preferencija VEOMA JAKA
Pravilo 2:
Ako je rastojanje MALO i čekanje SREDNJE
Tada je preferencija JAKA
Pravilo 3:
Ako je rastojanje MALO i čekanje VELIKO
Tada je preferencija SREDNJA
Pravilo 4:
Ako je rastojanje SREDNJE i čekanje MALO
Tada je preferencija SREDNJA

Rule 5:
If the distance is MEDIUM and the waiting is MEDIUM
Then the preference is MEDIUM
Rule 6:
If the distance is MEDIUM and the waiting is LONG
Then the preference is WEAK
Rule 7:
If the distance is LONG and the waiting is SHORT
Then the preference is MEDIUM
Rule 8:
If the distance is LONG and the waiting is MEDIUM
Then the preference is WEAK
Rule 9:
If the distance is LONG and the waiting is LONG
Then the preference is VERY WEAK

Approximate reasoning algorithm applies for all available vehicles by schedule of belonging of priority group: first is applied for vehicle from first group, then from second and then from third group. Each vehicle gets preference index value, as output value of approximate reasoning algorithm, and that's value of rankness of dispatcher's will to give him a request. Vehicles from each group are ranked based on preference index value. At this step of fuzzy system, it is possible to make choise of vehicle for realization of new request according to maximum Preference Index value in priority group of vehicles. When there are no available vehicles in all groups or when no vehicles can fulfill conditions for receiving new requests, than the transport request is dismissed.

Step 3:Design new vehicle route
When a vehicle is chosen to realize new request, then the vehicle new route is projected, which will consider request *i*. On figure 4 is shown the route of vehicle which considers nodes k, j, h, l, m. On the figure is shown new request *i*, which should be added to existing route.

Pravilo 5:
Ako je rastojanje SREDNJE i čekanje SREDNJE
Tada je preferencija SREDNJA
Pravilo 6:
Ako je rastojanje SREDNJE i čekanje VELIKO
Tada je preferencija SLABA
Pravilo 7:
Ako je rastojanje VELIKO i čekanje MALO
Tada je preferencija SREDNJA
Pravilo 8:
Ako je rastojanje VELIKO i čekanje SREDNJE
Tada je preferencija SLABA
Pravilo 9:
Ako je rastojanje VELIKO i čekanje VELIKO
Tada je preferencija VEOMA SLABA

Algoritam aproksimativnog rezonovanja se primenjuje za sva raspoloživa vozila po redosledu pripadnosti prioritetnoj grupi: prvo se primenjuje za vozila iz prve grupe, zatim iz druge i na kraju iz treće grupe. Kao izlazni podatak algoritma aproksimativnog rezonovanja, za svako vozilo se dobija vrednost indeksa preferencije, odnosno, mera jačine odluke dispečera da mu dodeli zahtev. Na osnovu vrednosti indeksa preferencije u okviru svake grupe se radi rangiranje vozila. U ovom koraku fazi sistema moguće je izvršiti izbor vozila za realizaciju novog zahteva prema maksimalnoj vrednosti indeksa preferencije u prioritetnoj grupi vozila. Kada nema raspoloživih vozila ni u jednoj grupi, odnosno, kada ni jedno vozilo ne ispunjava uslove za preuzimanje novog zahteva, tada zahtev za prevozom dobija otkaz.

Step 3:Projektovanje nove rute vozila
Kada se neko vozilo izabere za realizaciju novog zahteva, tada se projektuje nova ruta vozila, koja će obuhvatiti zahtev *i*. Na slici 4 prikazana je ruta vozila, koja obuhvata čvorove k, j, h, l, m. Na slici je prikazan novi zahtev za prevozom *i*, koga treba dodati na postojeću rutu.

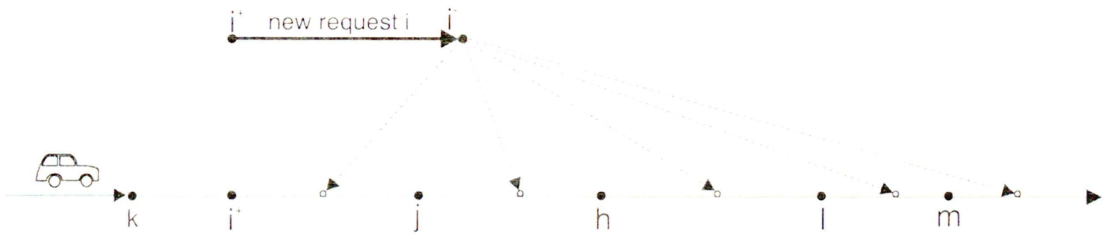

Figure 4 Planned vehicle route and new request i
slika 4 Planirana ruta vozila i novi zahtev za prevozom i

Node whish is origin of request i^+ is added to the route immediately after actual location, and node i^- can be added to the vehicle's route on different ways. Various versions of adding node i^- presents various vehicle's routes. For each route is necessary that increasing of time travel, made by output of request i from vehicle, doesn't react on request's time limits, already given to the vehicle. If increasing of time travel leads to violating time limits of other requests, then that combination is being dismissed.

Criteria for design new route are:

- Average increase of travel time, and
- Average increase of accomplished request's route (passengers), which are in the vehicle

Average increase of request's travel time can be "small", "medium" or "big" and can be presented by adequate fuzzy groups. Average increase of accomplished request's route can also be "small", "medium" or "big" and is described by fuzzy groups. Preference rankness of decision maker is shown by Preference Index, whose value can be from 0 to 1. With increase of preference, will rankness of decision makers to choose specified route of vehicle also increases.

Approximate reasoning algorithm for design route of vehicle, developed in this paper, consists of 9 rules:

Rule 1:
If the increase of time is SMALL and the increase of route is SMALL
Then the preference is VERY STRONG
Rule 2:
If the increase of time is SMALL and the increase of route is MEDIUM
Then the preference is STRONG
Rule 3:
If the increase of time is SMALL and the increase of route is BIG
Then the preference is STRONG
Rule 4:
If the increase of time is MEDIUM and the increase of route is SMALL
Then the preference is MEDIUM
Rule 5:
If the increase of time is MEDIUM and the increase of route is MEDIUM
Then the preference is MEDIUM

Čvor koji je početak zahteva i^+ dodaje se na rutu odmah posle trenutne lokacije, a čvor i^- može se na različite načine dodati na rutu vozila. Različite kombinacije dodavanja čvora i^- predstavljaju različite rute vozila. Za svaku rutu neophodno je da povećanje vremena putovanja, koje nastaje izlazom zahteva i iz vozila, ne utiče na vremenska ograničenja zahteva, koji su prethodno dodeljeni vozilu. Ako povećanje vremena putovanja dovodi do kršenja vremenskih ograničenja drugih zahteva, tada se ta kombinacija odbacuje.

Kriterijumi projektovanja nove rute vozila su:

- Prosečno povećanje vremena putovanja, i
- Prosečno povećanje pređenog puta zahteva (putnika), koji su u vozilu.

Prosečno povećanje vremena putovanja zahteva može biti "malo", "srednje" ili "veliko" i može se predstaviti odgovarajućim fazi skupovima. Takođe, prosečno povećanje pređenog puta zahteva može biti "malo", "srednje" ili "veliko" i opisuje se fazi skupovima. Jačina preferencije donosioca odluke se izražava indeksom preferencije, čija je vrednost od 0 do 1. Sa porastom indeksa preferencije raste i jačina želje donosioca odluke za izborom određene rute vozila.

Algoritam aproksimativnog rezonovanja za projektovanje rute vozila, razvijen u ovom radu, sastoji se od sledećih 9 pravila:

Pravilo 1:
Ako je povećanje vremena MALO i povećanje puta MALO
Tada je preferencija VEOMA JAKA
Pravilo 2:
Ako je povećanje vremena MALO i povećanje puta SREDNJE
Tada je preferencija JAKA
Pravilo 3:
Ako je povećanje vremena MALO i povećanje puta VELIKO
Tada je preferencija JAKA
Pravilo 4:
Ako je povećanje vremena SREDNJE i povećanje puta MALO
Tada je preferencija SREDNJA
Pravilo 5:
Ako je povećanje vremena SREDNJE i povećanje puta SREDNJE
Tada je preferencija SREDNJA

Rule 6:
If the increase of time is MEDIUM and the increase of route is BIG
Then the preference is WEAK
Rule 7:
If the increase of time is BIG and the increase of route is SMALL
Then the preference is WEAK
Rule 8:
If the increase of time is BIG and the increase of route is MEDIUM
Then the preference is VERY WEAK
Rule 9:
If the increase of time is BIG and the increase of route is BIG
Then the preference is VERY WEAK

Criteria values for each route are determined before entering the approximate reasoning algorithm: average increase of travel time and average increase of accomplished request's route in vehicle. We enter the approximate reasoning algorithm with these criteria values. Value of preference index for each route, which can be created by giving new request to vehicle, comes as output value of algorithm. The route that has highest value of preference index is taken for new vehicle's route. If vehicle chosen in previous step didn't have any possible route that fulfill request's time limit in vehicle, then the same model step is repeated for the next ranked vehicle from the same or next priority group. If there is no route that fulfill request's time limit in vehicle for all available vehicles, than the transport request *i* must be dismissed.

Step 4: Calculation of working indices
At the end of work you get group of realized and group of dismissed transport requests and route of vehicles through which vehicles were going during the day as output value of fuzzy system. Quantitative characteristics of carrier's work organization are indices of requests' services quality and indices of fleet's work.

Indices of requests' services quality are calculated for every accomplished request and consider: total time of request's accomplishment, travel time, standing time, coefficient of time increase and coefficient of increase of distance. An index of car fleet work are calculated for every vehicle separately and considers indices of exploitation of accomplished route and indices of exploitation of time: accomplished distance with

Pravilo 6:
Ako je povećanje vremena SREDNJE i povećanje puta VELIKO
Tada je preferencija SLABA
Pravilo 7:
Ako je povećanje vremena VELIKO i povećanje puta MALO
Tada je preferencija SLABA
Pravilo 8:
Ako je povećanje vremena VELIKO i povećanje puta SREDNJE
Tada je preferencija VEOMA SLABA
Pravilo 9:
Ako je povećanje vremena VELIKO i povećanje puta VELIKO
Tada je preferencija VEOMA SLABA

Pre ulaza u algoritam aproksimativnog rezonovanja, za svaku moguću kombinaciju rute određuju se vrednosti kriterijuma: prosečno povećanje vremena putovanja i prosečno povećanje pređenog puta, zahteva u vozilu. Sa ovim vrednostima kriterijuma ulazi se u algoritam aproksimativnog rezonovanja. Kao izlazni podatak algoritma dobija se vrednost indeksa preferencije za svaku rutu, koja može nastati dodavanjem novog zahteva vozilu. Za novu rutu vozila se uzima ruta koja ima najveću vrednost indeksa preferencije. Ako vozilo, koje je izabrano u prethodnom koraku, nije imalo ni jednu moguću rutu, koja zadovoljava vremenska ograničenja zahteva u vozilu, tada se ovaj korak modela ponavlja za sledeće rangirano vozilo iz iste ili sledeće prioritetne grupe. Ako ni za jedno od raspoloživih vozila ne postoji ruta, koja zadovoljava vremenska ograničenja zahteva u vozilu, tada zahtev za prevozom *i* mora dobiti otkaz.

Step 4: Izračunavanje pokazatelja rada
Na kraju rada, kao izlazni rezultat fazi sistema dobija se skup realizovanih i skup otkazanih zahteva za prevozom i rute vozila, kojima su se vozila kretala u toku dana. Kvantitativne karakteristike organizacije rada prevozioca su pokazatelji kvaliteta opsluge zahteva i pokazatelji rada voznog parka.

Pokazatelji kvaliteta opsluge zahteva se izračunavaju za svaki realizovani zahtev i obuhvataju: ukupno vreme realizacije zahteva, vreme prevoza, vreme stajanja, koeficijent povećanja vremena i koeficijent povećanja pređenog puta. Pokazatelji rada voznog parka se izračunavaju za svako vozilo i obuhvataju pokazatelje iskorišćenja pređenog puta i pokazatelje iskorišćenja vremena: pređeni put sa

passengers, accomplished distance without passengers, travel time with passengers, travel time without passengers, standing time, etc. Values of group of indices are got at the end of the day, based on which working effects and quality of given transport services can be evaluated.

6 CONCLUSION

In this work is presented fuzzy system for design vehicle's route in dynamic Dial-A-Ride system. Fuzzy system was tested on large number of numeric examples, which represents one carrier's work day. Test showed that developed fuzzy system can be successfully applied in defined conditions. Executing of fuzzy system is very quick and decisions on choise of vehicle and route of vehicle are made within few seconds.

Use of fuzzy logic and approximate reasoning algorithms showed as very successful for solving problems of design route in real time. Optimized and heuristic methods are very hard or even impossible to apply in modeling of dispatcher's behavior in real time and for solving problem of big dimensions (1000 travel requests during the day). Fuzzy logic provided modeling of dispatcher's system of deciding and getting quick and qualitative decisions. Use of fuzzy logic shows many advantages over optimizing method: very quick solution getting, great dimension of solving problem, simple modeling of dispatcher's reasoning, possibility of implementing a huge number of limitations in mathematic model. Approaches based on fuzzy logic provide applying in solving problems with great dimensions in real time, with fulfilling criteria of quick work and quality of given solutions.

putnicima, pređeni put bez putnika, vreme putovanja sa putnicima, vreme putovanja bez putnika, vreme stajanja, i dr. Na kraju radnog dana dobijaju se vrednosti skupa pokazatelja, na osnovu kojih je moguće oceniti efekte rada i kvaliteta pruženih prevoznih usluga.

6 ZAKLJUČAK

U radu prikazan fazi sistem za projektovanje ruta vozila u dynamic Dial-a-Ride sistemu. Fazi sistem je testiran na velikom broju numeričkih primera, koji predstavljaju jedan radni dan prevozioca. Testiranja su pokazala da se razvijeni fazi sistem može uspešno primeniti u konkretnim uslovima. Izvršavanje fazi sistema je veoma brzo i odluke o izboru vozila i rute vozila se dobijaju za nekoliko sekundi.

Primena fazi logike i algoritama aproksimativnog rezonovanja se pokazala kao veoma uspešna za rešavanje problema projektovanja ruta u realnom vremenu. Optimizacione ili heurističke metode je veoma teško ili nemoguće primeniti za modeliranje ponašanja dispečera u realnom vremenu i za rešavanje problema velikih dimenzija (1000 zahteva za prevozom u toku dana). Fazi logika je omogućila modeliranje dispečerskog sistema odlučivanja i dobijanje brzih i kvalitetnih odluka. Primena fazi logike pokazuje niz prednosti u odnosu na optimizacione metode: veoma brzo dobijanje rešenja, velike dimenzije rešavanih problema, jednostavno modeliranje dispečerskog rasuđivanja, mogućnost ugrađivanja velikog broja ograničenja u matematički model. Pristupi bazirani na fazi logici omogućavaju primenu u rešavanju problema velikih dimenzija u realnom vremenu zadovoljavajući kriterijume brzine rada i kvaliteta dobijenih rešenja.

REFERENCES / LITERATURA

[1] Bodin, L., Golden, B.: *Classification in vehicle routing and scheduling. Networks*, 11, 97-108, 1981.

[2] Desrosiers, J., Soumis, F., Desrochers, M., Sauve, M.: *Methods for Routing with Time Windows.* European Journal of Operational Research, 23, 235-245, 1986.

[3] Kaufmann, A., Gupta, M. M.: *Introduction to Fuzzy Arithmetic.* Van Nostrand Reinhold Company, New York, 1985.

[4] Kikuchi, S.: *Scheduling of demand Responsive Transit Vehicles.* Journal of Transportation Engineering, 110, 511-520, 1984.

[5] Kikuchi, S.: *Vehicle Routing and Scheduling Development for Transportation of Elderly and Handicapped Persons.* Transportation Quarterly, 41, 207-227, 1987.

[6] Kikuchi, S., Donnely, R.: *Scheduling Demand-Responsive Transportation Vehicles using Fuzzy Set Theory.* Journal of Transportation Engineering, 118, 430-440, 1992.

[7] Psaraftis, H.: *A dynamic programming solution to the single vehicle many-to-many immediate request dial-a-ride problem.* Transportation Science, 2, 130-154, 1980.

[8] Psaraftis, H.: *An Exact Algorithm for the Single-Vehicle Many-to-many Dial-a-ride problem with Time Windows.* Transportation Science, 17, 351-357, 1983.

[9] Radivojević, G.: *Multidisciplinary approach to optimization fleet management.* MS Thesis, Center for Multidisciplinary Studies of the Belgrade University, Belgrade, 1992.

[10] Radivojević, G.: *Fuzzy systems for traffic route design.* PhD Thesis, Faculty of Transport and Traffic Engineering, Belgrade, 2002.

[11] Sexton, T., Bodin, L.: *Optimizing Single Vehicle Many-to-Many Operations with Desired Delivery Times: I. Scheduling.* Transportation Science, 19, 378-410, 1985.

[12] Sexton, T., Bodin, L.: *Optimizing Single Vehicle Many-to-Many Operations with Desired Delivery Times: II. Routing.* Transportation Science, 19, 411-435, 1985.

[13] Solomon, M., Desrosiers, J.: *Time Window Constrained Routing and Scheduling Problems.* Transportation Science, 22, 1-13, 1988.

[14] Stein, D.: *Scheduling dial-a-ride transportation systems.* Transportation Science, 12, 232-249, 1978.

[15] Teodorović, D.: *Transportation Networks Analysis.* University of Belgrade, Belgrade, 1996.

[16] Teodorović, D., Kikuchi, S.: *Application of fuzzy sets theory to the saving based vehicle routing algorithm.* Civil Engineering Systems, 8, 87-93, 1991.

[17] Teodorović, D., Kikuchi, S.: *Elements of Fuzzy Set Theory with Applications in Transportation Engineering.* University of Belgrade, Belgrade, 1991, 1994.

[18] Teodorović, D., Pavković, G.: *The fuzzy set theory approach to the vehicle routing problem when demand at nodes is uncertain.* Fuzzy Sets and Systems, 82, 307-317, 1996.

[19] Teodorović, D., Radivojević, G.: *Fuzzy Logic Approach to the Dynamic Dial-a-Ride Problem.* 9th Mini EURO Conference: Fuzzy Sets in Traffic and Transport Systems, Budva, Yugoslavia, 1997.

[20] Vukadinović, K., Teodorović, D.: *A Fuzzy Approach to the Vessel Dispatching problem.* European Journal of Operational Research, 76, 155-164, 1994.

[21] Zadeh, L.A.: *Fuzzy Sets.* Information and Control, 8, 338-353, 1965.

[22] Zimmermann, H.J.: *Fuzzy Sets.* Decision Making, and Expert Systems", Kluwer Academic Publishers, Boston, 1987.

Reviewal / Recenzija: Ing. Michal Balog CSc