Title: CONGESTIVE COLLAPSE AVOIDANCE IN A DYNAMIC DIAL-A-RIDE SYSTEM

Abstract: The invention allows avoiding congestive collapse in a dynamic dial-a-ride system. In response to a trip request received in a dispatching unit of a dynamic dial-a-ride system, vehicles of the dynamic dial-a-ride system are enquired whether they are available to accept the requested trip. In response to the number of the vehicles available to accept the requested trip being equal or more than the predetermined threshold, the trip request is rejected. Only in response to the number of the vehicles available to accept the requested trip being equal or more than the predetermined threshold, the trip request is accepted, and the requested trip is allocated to one of the available vehicles.

Fig. 1
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CONGESTIVE COLLAPSE AVOIDANCE IN A DYNAMIC DIAL-A-RIDE SYSTEM

FIELD OF THE INVENTION

The present invention relates to dynamic dial-a-ride systems. In particular, the present invention relates to congestive collapse avoidance in dynamic dial-a-ride systems.

BACKGROUND OF THE INVENTION

A dial-a-ride system is a transport system comprising vehicles (e.g. minivans) used to transport customers, a central dispatching system assigning trips to the vehicles, and customers asking for a transport service in real-time. In other words, the set of vehicles provides a demand-responsive transport service. The vehicles can be shared similarly to buses, while schedules and routes are chosen ad hoc.

That is, the passengers share the vehicles in such a way that simultaneous trips can be conducted by a single vehicle thus enabling an efficient utilization of the transport capacity of the system.

The dispatching/reservation/control system is typically operated by a traffic operator (e.g. a taxi firm or a bus company). The vehicles may be owned by the same operator or some other party. The passengers are customers who request trips with time limits (e.g. a latest arrival time). The system honours the time limits, i.e. promises given upon trip reservation are kept.

A dial-a-ride system may be either dynamic or non-dynamic. Herein, the term "non-dynamic" refers to a type of the dial-a-ride system which is non-real time with advance reservations (e.g. for elderly people). In such a case, one can optimize the routes offline.
In contrast, the term "dynamic" refers herein to a type of the dial-a-ride system which is real-time or at least near real-time. That is, a fleet of vehicles provides on-demand type of shared ride service, and the routes of the vehicles are constantly changed in real-time (or at least near real-time) in order to accommodate new trip requests. Typically, the trip requests have some time constraints (time windows), e.g. on the latest delivery time or a pick-up window. Each requested trip is assigned to such a vehicle the already existing route of which matches the best with the newly requested trip. In practice, trip allocation is typically a heuristic decision.

Hence, the dynamic real-time operation requires on-line routing decisions and real-time (wireless) communication between i) the vehicles and the central system, and ii) the customers and the central system.

However, there is a significant drawback with prior art dynamic dial-a-ride systems in that the performance of such a system may drop significantly when the trip request load increases beyond the capacity of the system. Herein, this is called congestive collapse. The congestive collapse is a consequence of the fact that the routes become highly un-optimal (e.g. long zigzag routes). Due to service promises, neither the routes nor customer assignment to the vehicles can be re-arranged, resulting in a state where a considerable fraction of the transport capacity of the fleet is wasted. In other words, service promises may bind a vehicle to a potentially suboptimal route. This problem is emphasized in a situation in which only one vehicle can accept a ride, and consequently the ride is also unconditionally assigned to it no matter how incompatible it is with the vehicle's current route.

To illustrate the above, let us consider an ideal model for a dial-a-ride system with n vehicles,
each having \( c \) passenger seats and a constant velocity of \( v \). Each stop takes a minimum time of \( t_{st} \) during which one or more passengers may enter or leave the vehicle. This stop time is understood to also include both acceleration and deceleration. As our aim is to model a dial-a-ride service, and not the resulting road traffic, we therefore assume that the vehicles operate freely in some convex subset of a plane.

For simplicity, we assume that trip requests, i.e. customers or tasks, arrive according to a Poisson process with rate \( \lambda \) and both the origin \( r_1 \) and destination \( r_2 \) of each trip are uniformly distributed in the given area (cf. Poisson point process). We assume that the trip, if accepted, must be completed before the latest feasible delivery time denoted by \( t_c \). Thus, a trip request is defined by a triple \((x; r_2; t_c)\). Let \( t_0 \) denote the request time and \( t_i \) the delivery time, so that \( t_i \leq t_c \). For \( t_c \) we use a linear model

\[
t_c = t_0 + a \cdot (\ell/v) + b
\]

(Equation 1)

where \( a \) and \( b \) are some constants, and \( \ell \) is Euclidean trip distance: \( \ell = |r_2 - r_1| \). Consequently, the time spent in the system, \( ti - t_0 \), is constrained by

\[
t_i - t_0 \leq a \cdot (\ell/v) + b
\]

(Equation 2)

The quantity \( ti - t_0 \) is referred to as the system time of a customer.

The trip request process is served by the fleet of \( n \) vehicles. When request rate \( \lambda \) is small, it is possible to accept all customers. However, as the request rate increases, at some point one has to start rejecting some requests due to a lack of transport capacity. The chosen parameter values used in the following numerical examples are as follows:
Area: a disk with 5 km radius, 
vehicles $n$: 500, each with 16 seats, 
velocity $v$: 10 m/s, 
stopping time $t_{st}$: 30 s, and 
delivery time window: $1.2 \cdot (l/v) + 10$ min.

Thus, a set of $n = 500$ vehicles support trip requests arriving with rate $\lambda$. For each trip request from $r_1$ to $r_2$, the latest feasible delivery time is given by $t_c = t_o + 1.2 \cdot \left( \frac{l}{v} \right) + 10$ minutes, where $t_o$ denotes the request time, $v = 10$ m/s denotes the vehicles' velocities, and $l$ denotes the direct trip distance: $l = |r_2 - r_1|$. Defining $t_c$ this way allows vehicles, e.g. to pick up new passengers while serving other passengers. Each stop also takes at least $t_{st} = 30$ seconds.

We consider an online problem where at the arrival of a trip request, a chosen control policy assigns the trip to a single vehicle and updates its route accordingly. The vehicle's route may be modified afterwards in response to a later trip request, but the vehicle assigned to a passenger remains the same. Moreover, the control policy must honor the given guarantees, i.e., passengers accepted must be delivered within the corresponding time windows according to Equation 2.

The heuristic control policies we consider are based on two quantities: (i) vehicle's route duration and (ii) passengers' system times. The former stands for the vehicle's current planning horizon, i.e., the time when the last passenger exits a given vehicle. The latter corresponds to the sum of a vehicle's passengers' system times according to the present plan. Note that one can also consider the remaining system times as no action can change the past. The actual control policies are the following:

- **min-RD** (minimum route duration) assigns the new trip to the (vehicle, route) -pair which can de-
liver both the new and its existing passengers fast-
est, i.e. the one with the shortest planning horizon;

- **min-ARD** (minimum difference in route dura-
tion) chooses the (vehicle, route) -pair serving the
new trip request with the smallest additional effort
(in time), i.e. a pair increasing a vehicle's planning
horizon by the smallest amount;

- **min-AST** (minimum difference in system
times) chooses the (vehicle, route) -pair yielding the
smallest difference between the sum of the passengers' system times before and after inclusion of the new
trip request; and

- **combined** (combined objective) is a weighted
sum of **min-ARD** and **min-AST**. That is, the (vehicle, route) -pair minimizing the sum $0.4 \cdot \text{min-ARD} + 0.6 \cdot \text{min-AST}$ is chosen.

These heuristic criteria are greedy in the sense that they do not take into account future events. Note that the route evaluation can be done lo-
cally for each vehicle facilitating a parallel evalua-
tion of routes, and that **min-RD** implements "load bal-
cancing" between the vehicles. The state of each vehi-
cle comprises a current location, a route (a sequence of waypoints), and passengers assigned to it. Thus,
increasing the number of vehicles and the mean number of passengers leads to a state-space explosion and one
has to resort to simulation experiments with heuristic control policies in order to analyze the system.

In an over provisioned system, where the num-
ber of vehicles $n$ is unnecessarily high, passengers
obtain good but expensive service. Consequently, it is
a mutual benefit to decrease the number of vehicles to
a level where all $n$ vehicles are in efficient use. In
an ideal situation this means that the average occu-
pancy of the vehicles is reasonably high, while the
passengers' system times still remain relatively close
to those obtained with private cars ("direct trips").
In such a situation, the dial-a-ride system offers an appealing service and can eventually displace part of the private cars thus also improving traffic congestion in an urban environment. However, when a system operates near the capacity limit, there is a constant danger that the demand suddenly increases to a level which leads to an overload situation.

As the performance evaluation of this system is beyond analytical means, we resort to simulations. Figure 3a illustrates the resulting performance with the 4 heuristic control policies described above. The system parameters are those given above. The x-axis corresponds to the offered load (trip requests per second), and on the y-axis we have the delivered passenger kilometers per vehicle hour corresponding to the total direct trip distance of accepted trips. In the simulations, we have used a warm-up time of 10 h and a simulation time of 20 h, which are more than adequate in the considered setting. We note that especially with the 3 most efficient control policies the passenger kilometer rate collapses dramatically at some point, as seen in Figure 3a. Thus increasing the trip request rate at some point, the offered load exceeds the capacity of the system, and the system's performance collapses. This type of a phenomenon, known as the congestive collapse, is obviously highly undesirable. With the studied control policies, the performance level after the collapse is quite similar, which suggests that the system eventually falls into a state where routes are inefficient. For the reference, in the example scenario, typical occupancy in the vehicles was constantly less than \( c = 16 \) seats and thus it does not affect the observed performance.

Therefore, an object of the present invention is to alleviate the problems described above and to introduce a solution that allows avoiding congestive collapse in a dynamic dial-a-ride system.
SUMMARY OF THE INVENTION

A first aspect of the present invention is a method of congestive collapse avoidance in a dynamic dial-a-ride system in which, in response to a trip request received in a dispatching unit of the dynamic dial-a-ride system, vehicles of the dynamic dial-a-ride system are enquired whether they are available to accept the requested trip. In response to the number of the vehicles available to accept the requested trip being less than a predetermined threshold, the trip request is rejected.

A second aspect of the present invention is a dispatching unit of a dynamic dial-a-ride system. The dispatching unit comprises an availability inquirer that is configured to enquire, in response to a received trip request, vehicles of the dynamic dial-a-ride system whether they are available to accept the requested trip. The dispatching unit further comprises a trip allocator that is configured to reject the trip request in response to the number of the vehicles available to accept the requested trip being less than a predetermined threshold.

A third aspect of the present invention is a dispatching means of a dynamic dial-a-ride system. The dispatching means comprises an availability enquiring means for enquiring, in response to a received trip request, vehicles of the dynamic dial-a-ride system whether they are available to accept the requested trip. The dispatching means further comprises a trip allocating means for rejecting the trip request in response to the number of the vehicles available to accept the requested trip being less than a predetermined threshold.

A fourth aspect of the present invention is a computer program comprising code adapted to cause the
following when executed on a dispatching unit of a dynamic dial-a-ride system:

- enquiring, in response to a trip request received in the dispatching unit of the dynamic dial-a-ride system, vehicles of the dynamic dial-a-ride system whether they are available to accept the requested trip; and

- in response to the number of the vehicles available to accept the requested trip being less than a predetermined threshold, rejecting the trip request.

In an embodiment of the invention, in response to the number of the vehicles available to accept the requested trip being equal or more than the predetermined threshold, the trip request is accepted; and the requested trip is allocated to one of the available vehicles.

In an embodiment of the invention, the predetermined threshold comprises an integer value $k$, such that the presence of $k$ available vehicles, on average, ensures that the best among them are able to accept a new trip request efficiently.

In an embodiment of the invention, a total number of vehicles is adapted based on the number of the vehicles available to accept the requested trip.

In an embodiment of the invention, at least one time window of the trip request is adjusted based on the number of the vehicles available to accept the requested trip.

In an embodiment of the invention, at least one of congestion and available transport capacity between two locations is gauged based on the number of the vehicles available to accept the requested trip.

In an embodiment of the invention, the computer program of the fourth aspect of the present invention is stored on a computer readable medium.

It is to be understood that the aspects and embodiments of the invention described above may be
used in any combination with each other. Several of the aspects and embodiments may be combined together to form a further embodiment of the invention. A method, a dispatching unit, a dispatching means or a computer program which is an aspect of the invention may comprise at least one of the embodiments of the invention described above.

The invention allows avoiding congestive collapse in a dynamic dial-a-ride system. Furthermore, the invention allows performing the congestive collapse avoidance in a manner that is elegant, robust and computationally lightweight.

**BRIEF DESCRIPTION OF THE DRAWINGS**

The accompanying drawings, which are included to provide a further understanding of the invention and constitute a part of this specification, illustrate embodiments of the invention and together with the description help to explain the principles of the invention. In the drawings:

- **Fig. 1** is a flow diagram illustrating a method according to an embodiment of the invention;
- **Fig. 2** is a block diagram illustrating a dispatching unit according to an embodiment of the invention as deployed in connection with a dynamic dial-a-ride system; and
- **Figs. 3a-3e** illustrate various simulation results.

**DETAILED DESCRIPTION OF THE INVENTION**

Reference will now be made in detail to the embodiments of the present invention, examples of which are illustrated in the accompanying drawings.

Figure 1 is a flow diagram illustrating a method of congestive collapse avoidance in a dynamic
At step 10, a trip request is received in a dispatching unit of a dynamic dial-a-ride system. In response to the received trip request, vehicles of the dynamic dial-a-ride system are enquired whether they are available to accept the requested trip, step 11. In response to the number of the vehicles available to accept the requested trip being less than a predetermined threshold in step 12, the trip request is rejected, step 13. However, in response to the number of the vehicles available to accept the requested trip being equal or more than the predetermined threshold in step 12, the trip request is accepted, step 14. Then, the requested trip is allocated to one of the available vehicles, step 15.

The predetermined threshold may comprise an integer value \( k \), such that the presence of \( k \) available vehicles, on average, ensures that the best among them are able to accept a new trip request efficiently.

Figure 2 is a block diagram illustrating a dispatching unit 210 according to an embodiment of the invention as deployed in connection with a dynamic dial-a-ride system 200.

The dynamic dial-a-ride system 200 comprises vehicles 221, 223, 225 (such as minivans) used to transport customers. However, it is to be understood that the present invention is not limited to minivans. Instead, any suitable vehicles may be employed.

Each vehicle 221, 223, 225 comprises wireless communication means 222, 224, 226 for communicating with the dispatching unit 210. A customer asking for a transport service in real-time has a terminal device 230 used to communicate with the dispatching unit 210.

The terminal device 230 may be wired or wireless. The terminal device 230 may be e.g. a mobile phone, a smartphone, a laptop computer, a desktop computer, a
fixed telephone, a tablet computer, or a PDA. In an embodiment of the invention, customers may use e.g. SMS (Short Message Service) messages to communicate with the dispatching unit 210. However, it is to be understood that the present invention is not limited to the above illustrative examples. Also, in some embodiments of the invention, the customer terminal device 230 and/or vehicle wireless communication means 222, 224, 226 may not communicate directly with the dispatching unit 210. Rather, there may be intermediate communication means (not illustrated in Figure 2) deployed between them.

The dynamic dial-a-ride system 200 further comprises the dispatching unit 210. The dispatching unit 210 comprises an availability inquirer 211 that is configured to enquire, in response to a received trip request, vehicles of the dynamic dial-a-ride system whether they are available to accept the requested trip. The dispatching unit 210 further comprises a trip allocator 212 that is configured to reject the trip request in response to the number of the vehicles available to accept the requested trip being less than a predetermined threshold. The trip allocator 212 is further configured to accept the trip request in response to the number of the vehicles available to accept the requested trip being equal or more than the predetermined threshold, and to allocate the requested trip to one of the available vehicles in such a case. Here, the predetermined threshold may comprise an integer value $k$, such that the presence of $k$ available vehicles, on average, ensures that the best among them are able to accept a new trip request efficiently.

The dispatching unit 210 may be comprised in e.g. a server computer or a cluster of servers. The dispatching unit 210, the availability inquirer 211 and/or the trip allocator 212 may be implemented as software, hardware or a combination of both.
In the following, the invention is further described with reference to various simulation results illustrated in Figures 3b-3e.

Let random variable $A_j$ denote the number of vehicles available to accept the $j^{th}$ trip request without violating any of the given guarantees (see Equation 2). Thus, when $A_j = 0$, no vehicle can accept the given customer who must therefore be rejected. Figure 3b shows the mean number of available vehicles per trip request, denoted by $E[A_j]$ , corresponding to the prior art basic situation similarly to Figure 3a. It can be seen from Figure 3b that with all the control policies the number of available vehicles drops to zero in response to congestion. With the 3 best control policies the drop is sudden.

This observation has led the inventors to propose an admission rule that rejects a request if there are less than $k$ vehicles available:

[R1]: Accept trip $j$ when $A_j \geq k$.

In contrast, the basic admission rule of prior art accepts a customer whenever possible:

[R0]: Accept trip $j$ when $A_j > 0$.

As shown next, the above admission rule R1 of the present invention works well enough in practice.

Essentially, the assumption is that if $k$ or more vehicles can handle a new customer, then the best among then can handle the customer well, i.e. it can exploit the synergies between the trips.

The resulting performance for a dial-a-ride system (with the same parameter values as those used in connection with Figure 3a on page 4) is illustrated in Figure 3c. The solid lines correspond to situation with the admission control rule R1 of the invention, and the dashed lines with rule R0 of prior art. For min-ARD, admission threshold $k = 10$ was used, and for other control policies $k = 20$. Intuitively, the steeper the drop with R0, the higher the threshold $k$ should
be. The chosen values for $k$ are roughly optimal in the example setting. It can be seen from Figure 3c that the collapse avoidance mechanism R1 of the invention clearly works well and manages to maintain the performance level after the congestive collapse point by choosing to accept only such trips which have synergies. The performance improvement can also be significant depending on the particular setting and the chosen parameter values. In our example with the combined control policy, the improvement over the collapsed state of $R_0$ at $\lambda = 2.2$ (1/s) is about 50%! With less flexible customers, the difference becomes also smaller, and vice versa.

Figure 3d illustrates again the mean number of available vehicles per request as a function of trip request rate $\lambda$. The solid lines correspond to rule R1 of the invention and dashed lines to rule $R_0$ of prior art. It can be seen from Figure 3d that rule R1 indeed ensures that $E[A]$ remains above or around the chosen threshold level $k$, thus making it possible for the system to operate properly without falling into any congestive collapse state.

Figure 3e illustrates how the trip request rejection probability behaves. The solid curves correspond to rule R1 of the invention and the dashed curves to rule $R_0$ of prior art. One can observe that in congestive collapse, the rejection probability suddenly jumps to some very high value, around 30% - 50% in this case, which clearly is unacceptable. Congestive collapse avoidance rule R1 manages to avoid this, resulting in a moderately increasing rejection probability.

To summarize, the above described invention allows avoiding congestive collapse in a dynamic dial-a-ride system in a manner that is elegant, robust and computationally lightweight. Furthermore, the disclosed availability quantity, $A_j$, can be also used (i)
for proactively adjusting/controlling the number of vehicles, and (ii) for estimating the free transport capacity between any two locations.

That is, the availability quantity $A_j$ can be also utilized in other ways:

1) To proactively adjust the fleet size $n$ in order to adapt to the current demand level. For example, when $A_j$ drops below a certain threshold, one may increase the number of vehicles, and vice versa.

2) To dynamically adjust the time windows in order to adapt especially to a higher demand that is detected by means of observing the values $A_j$ obtains. More concretely, for each trip request, the system may require e.g. at least $k=10$ valid offers before a trip request can be admitted. To this end, the time window constraints of the given trip request are relaxed until the minimum of $k$ vehicles can accept the request, and hence one or more of those vehicles can implement the trip efficiently (with high probability). Then, the trip, together with the relaxed time constraints, is assigned to the vehicle that appears to be in the best position to accept the trip according to the used heuristic cost function. It is to be understood that this is simply an alternative way to ensure that the criteria "at least $k$ vehicles available" is fulfilled for each trip request admitted to the system.

3) To gauge the congestion and/or available transport capacity between two locations, in general. Such information can also be used to support, e.g. a pricing scheme.

The exemplary embodiments can include, for example, any suitable servers, workstations, PCs, laptop computers, personal digital assistants (PDAs), Internet appliances, handheld devices, cellular telephones, smart phones, wireless devices, other devices, and the like, capable of performing the processes of the exemplary embodiments. The devices and subsystems
of the exemplary embodiments can communicate with each other using any suitable protocol and can be implemented using one or more programmed computer systems or devices.

One or more interface mechanisms can be used with the exemplary embodiments, including, for example, Internet access, telecommunications in any suitable form (e.g., voice, modem, and the like), wireless communications media, and the like. For example, employed communications networks or links can include one or more wireless communications networks, cellular communications networks, 3G communications networks, Public Switched Telephone Network (PSTNs), Packet Data Networks (PDNs), the Internet, intranets, a combination thereof, and the like.

It is to be understood that the exemplary embodiments are for exemplary purposes, as many variations of the specific hardware used to implement the exemplary embodiments are possible, as will be appreciated by those skilled in the hardware and/or software art(s). For example, the functionality of one or more of the components of the exemplary embodiments can be implemented via one or more hardware and/or software devices.

The exemplary embodiments can store information relating to various processes described herein. This information can be stored in one or more memories, such as a hard disk, optical disk, magneto-optical disk, RAM, and the like. One or more databases can store the information used to implement the exemplary embodiments of the present inventions. The databases can be organized using data structures (e.g., records, tables, arrays, fields, graphs, trees, lists, and the like) included in one or more memories or storage devices listed herein. The processes described with respect to the exemplary embodiments can include appropriate data structures for storing data collected
and/or generated by the processes of the devices and subsystems of the exemplary embodiments in one or more databases.

All or a portion of the exemplary embodiments can be conveniently implemented using one or more general purpose processors, microprocessors, digital signal processors, micro-controllers, and the like, programmed according to the teachings of the exemplary embodiments of the present inventions, as will be appreciated by those skilled in the computer and/or software art(s). Appropriate software can be readily prepared by programmers of ordinary skill based on the teachings of the exemplary embodiments, as will be appreciated by those skilled in the software art. In addition, the exemplary embodiments can be implemented by the preparation of application-specific integrated circuits or by interconnecting an appropriate network of conventional component circuits, as will be appreciated by those skilled in the electrical art(s).

Thus, the exemplary embodiments are not limited to any specific combination of hardware and/or software.

Stored on any one or on a combination of computer readable media, the exemplary embodiments of the present inventions can include software for controlling the components of the exemplary embodiments, for driving the components of the exemplary embodiments, for enabling the components of the exemplary embodiments to interact with a human user, and the like. Such software can include, but is not limited to, device drivers, firmware, operating systems, development tools, applications software, and the like. Such computer readable media further can include the computer program product of an embodiment of the present inventions for performing all or a portion (if processing is distributed) of the processing performed in implementing the inventions. Computer code devices of the exemplary embodiments of the present inventions can
include any suitable interpretable or executable code mechanism, including but not limited to scripts, interpretable programs, dynamic link libraries (DLLs), Java classes and applets, complete executable programs, Common Object Request Broker Architecture (CORBA) objects, and the like. Moreover, parts of the processing of the exemplary embodiments of the present inventions can be distributed for better performance, reliability, cost, and the like.

As stated above, the components of the exemplary embodiments can include computer readable medium or memories for holding instructions programmed according to the teachings of the present inventions and for holding data structures, tables, records, and/or other data described herein. Computer readable medium can include any suitable medium that participates in providing instructions to a processor for execution. Such a medium can take many forms, including but not limited to, non-volatile media, volatile media, transmission media, and the like. Non-volatile media can include, for example, optical or magnetic disks, magnetooptical disks, and the like. Volatile media can include dynamic memories, and the like. Transmission media can include coaxial cables, copper wire, fiber optics, and the like. Transmission media also can take the form of acoustic, optical, electromagnetic waves, and the like, such as those generated during radio frequency (RF) communications, infrared (IR) data communications, and the like. Common forms of computer-readable media can include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, any other suitable magnetic medium, a CD-ROM, CD±R, CD±RW, DVD, DVD-RAM, DVD±RW, DVD±R, HD DVD, HD DVD-R, HD DVD-RW, HD DVD-RAM, Blu-ray Disc, any other suitable optical medium, punch cards, paper tape, optical mark sheets, any other suitable physical medium with patterns of holes or other optically recognizable indi-
cia, a RAM, a PROM, an EPROM, a FLASH-EPROM, any other suitable memory chip or cartridge, a carrier wave or any other suitable medium from which a computer can read.

While the present inventions have been described in connection with a number of exemplary embodiments, and implementations, the present inventions are not so limited, but rather cover various modifications, and equivalent arrangements, which fall within the purview of prospective claims.
CLAIMS

1. A method of congestive collapse avoidance in a dynamic dial-a-ride system, comprising:
   enquiring (11), in response to a trip request received in a dispatching unit of the dynamic dial-a-ride system, vehicles of the dynamic dial-a-ride system whether they are available to accept the requested trip;
   characterized in further comprising:
   in response to the number of the vehicles available to accept the requested trip being less than a predetermined threshold, rejecting (13) the trip request.

2. The method according to claim 1, further comprising:
   in response to the number of the vehicles available to accept the requested trip being equal or more than the predetermined threshold, accepting (14) the trip request; and
   allocating (15) the requested trip to one of the available vehicles.

3. The method according to claim 1 or 2, wherein the predetermined threshold comprises an integer value \( k \), such that the presence of \( k \) available vehicles, on average, ensures that the best among them are able to accept a new trip request efficiently.

4. The method according to any of the claims 1-3, wherein a total number of vehicles is adapted based on the number of the vehicles available to accept the requested trip.

5. The method according to any of the claims 1-4, wherein at least one time window of the trip request is adjusted based on the number of the vehicles available to accept the requested trip.

6. The method according to any of the claims 1-5, wherein at least one of congestion and available transport capacity between two locations is gauged.
based on the number of the vehicles available to accept the requested trip.

7. A dispatching unit (210) of a dynamic dial-a-ride system (200), comprising:
   an availability inquirer (211) configured to enquire, in response to a received trip request, vehicles (221, 223, 225) of the dynamic dial-a-ride system (200) whether they are available to accept the requested trip;
   characterized in further comprising:
   a trip allocator (212) configured to reject the trip request in response to the number of the vehicles available to accept the requested trip being less than a predetermined threshold.

8. The dispatching unit (210) according to claim 7, wherein the trip allocator (212) is further configured to:
   accept the trip request in response to the number of the vehicles available to accept the requested trip being equal or more than the predetermined threshold; and
   allocate the requested trip to one of the available vehicles.

9. The dispatching unit (210) according to claim 7 or 8, wherein the predetermined threshold comprises an integer value $k$, such that the presence of $k$ available vehicles, on average, ensures that the best among them are able to accept a new trip request efficiently.

10. The dispatching unit (210) according to any of the claims 7-9, further configured to adapt a total number of vehicles based on the number of the vehicles available to accept the requested trip.

11. The dispatching unit (210) according to any of the claims 7-10, further configured to adjust at least one time window of the trip request based on
the number of the vehicles available to accept the requested trip.

12. The dispatching unit (210) according to any of the claims 7-11, further configured to gauge at least one of congestion and available transport capacity between two locations based on the number of the vehicles available to accept the requested trip.

13. A computer program comprising code adapted to cause the following when executed on a dispatching unit of a dynamic dial-a-ride system:

enquiring (11), in response to a trip request received in the dispatching unit of the dynamic dial-a-ride system, vehicles of the dynamic dial-a-ride system whether they are available to accept the requested trip;

characterized in the code further adapted to cause the following when executed:

in response to the number of the vehicles available to accept the requested trip being less than a predetermined threshold, rejecting (13) the trip request.

14. The computer program according to claim 13, the code further adapted to cause the following when executed:

in response to the number of the vehicles available to accept the requested trip being equal or more than the predetermined threshold, accepting (14) the trip request; and

allocating (15) the requested trip to one of the available vehicles

15. The computer program according to claim 13 or 14, wherein the predetermined threshold comprises an integer value k, such that the presence of k available vehicles, on average, ensures that the best among them are able to accept a new trip request efficiently.
16. The computer program according to any of the claims 13-15, wherein a total number of vehicles is adapted based on the number of the vehicles available to accept the requested trip.

17. The computer program according to any of the claims 13-16, wherein at least one time window of the trip request is adjusted based on the number of the vehicles available to accept the requested trip.

18. The computer program according to any of the claims 13-17, wherein at least one of congestion and available transport capacity between two locations is gauged based on the number of the vehicles available to accept the requested trip.

19. The computer program according to any of the claims 13-18, wherein the computer program is stored on a computer readable medium.
Fig. 1
Fig. 2
Prior Art

Fig. 3a
Prior Art

Fig. 3b
Fig. 3c
Fig. 3e
## INTERNATIONAL SEARCH REPORT

### A. CLASSIFICATION OF SUBJECT MATTER

According to International Patent Classification (IPC) or to both national classification and IPC

### B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G06Q, G08G

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Fl, SE, NO, DK

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI, BIOSIS, BOCA, COMPDx, EMBASE, INSPEC, MEDLINE, NPL, TDB, XP3GPP, XPAIP, XPESP, XPETS, XPI3E, XPIEE, XPIETF, XPIOP, XPIPcom, XPJPEG, XPMISC, XPOAC, XPRD, XPTK, Google Scholar

### c. DOCUMENTS CONSIDERED TO BE RELEVANT

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<td>PUREZA, V., &amp; LAPORTE, G., 'Waiting and Buffering Strategies for the Dynamic Pickup and Delivery Problem with Time Windows'. INFOR, August 2008, Vol. 46, No. 3, p. 165 - 175, ISSN 0311-5976, EISSN 1986-0615, DOI: 10.1016/infor.46.3.165 abstract; section 1; section 3 &quot;The problem&quot;; sections 3.1, 5.7</td>
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- Special categories of cited documents:
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Date of the actual completion of the international search

15 September 2011 (15.09.2011)

Date of mailing of the international search report

27 September 2011 (27.09.2011)

Name and mailing address of the ISA/FI

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Authorized officer

Antti Salmela

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<td>MES, M. et al., 'Comparison of agent-based scheduling to look-ahead heuristics for real-time transportation problems'. European Journal of Operational Research, August 2007, Vol. 181, No. 1, p. 59 - 75, ISSN 0377-2217, DOI: 10.1016/j.ejor.2006.02.051, XP 005908897 abstract; section 1, paragraph 5; section 2.1, paragraph 1; sections 2.3, 3.2; section 4.3, paragraph 3; section 5.2; section 6, paragraphs 2 - 3</td>
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<td>GB 2397683 A (OLMI GIUSEPPE ANTONIO) 28 July 2004 (28.07.2004) abstract; page 36, paragraph 5; page 51, paragraph 7 - page 52, paragraph 1; page 60, paragraph 1</td>
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<td>DIANA, M. et al., A model for the fleet sizing of demand responsive transportation services with time windows'. Transportation Research, Part B, September 2006, Vol. 40, No. 8, p. 651 - 666, ISSN 0191-2615, DOI: 10.1016/j.trb.2005.09.005, XP 025069155 abstract; section 1, paragraphs 1, 4, 5; sections 4.1, 5.3, 6</td>
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<td>KOHL, N. et al., '2-Path Cuts for the Vehicle Routing Problem with Time Windows'. Transportation Science, February 1999, Vol. 33, No. 1, p. 101 - 116, ISSN 0041-1655, DOI: 10.1287/trsc.33.1.101 abstract; page 101 - page 102, left column, paragraph 4; section 1.2, paragraph 3; section 3.1</td>
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## International Search Report

### International application No.
PCT/FI201 1/050548

### Classification of Subject Matter

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