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Development of an integrated flexible transport systems platform for rural areas using argumentation theory

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ABSTRACT

Flexible transport systems (FTS) offer a promising approach to improving the efficiency and performance of passenger transportation services. FTS aim to provide passengers with flexibility in choosing routes, times, modes of transport, service provider and payment systems. In order to achieve this additional flexibility, a well-designed FTS integrate different modes of transport, possibly spanning multiple service providers, to provide more sophisticated, comfortable and cost-effective transport opportunities. The concept of flexible transport is not new; many existing systems, including shared taxicabs, Dial-A-Ride services, and car-clubs, contain elements of such a system. In this paper, we concentrate on FTS within rural areas, which generally suffer from lack of service availability and demand uncertainties, and for which existing FTS solutions are not well suited. We present an agent-based flexible transport systems platform developed using argumentation theory. Formal argumentation is a powerful technique borrowed from artificial intelligence, and in this context is used to weigh-up the conflicting choices available to both passengers and service providers. The resultant platform for FTS in rural areas acts as a virtual transport market place that would more effectively match existing demand and supply for transport services than existing solutions.

1. Introduction

The lack of transport options for rural dwellers reduces accessibility to a range of critical basic services and amenities, as these are typically located in distant centres; improving transportation options would improve the accessibility and social inclusion of those in rural areas (Nutley, 2003). The characteristics of rural areas present some barriers to improving and developing public transportation. Examples of such characteristics are: (1) rural dwellings and other centres of attraction are distributed over large areas; (2) population density is low and so potential passenger numbers are limited; and (3) level of demand for transport is unpredictable. Meeting the transport needs of rural dwellers with conventional public transport would require the provision of public transport with frequent schedule and widespread coverage; such an approach is financially unjustifiable for the passenger numbers attainable.

A flexible transport system has been identified as one of the promising solutions for rural transport (Mulley and Nelson, 2009). Over the last 10 years, many flexible transport services have been established; examples include shared taxicabs, shuttle vans, dial-a-ride services, paratransit services, ring-and-ride services, dial-up buses, lift shares, and car-clubs (Li and Quadrifoglio, 2010). However, these are largely introduced as stand-alone services often to cater for a specific group of the population or to fill a specific need. Further, such rural FTS are costly and typically run in a somewhat rigid manner, offering passengers limited travel times. There is little or no integration between services and so such FTS generally make inefficient use of transport resources. As a result they may not offer a comprehensive network solution which could fill the gaps in conventional public transport in rural areas.

An integrated flexible transport systems (FTS) can be defined as a system that provides a desirable level of flexibility for passengers when choosing routes, time of travel, modes of transport, service providers, and payment systems while integrating different available services in order to improve the efficiency and performance of a transport service (Palmer, Dessouky, and Abdelmaguid, 2004).

The following propositions can improve existing FTS in rural areas to some extent by addressing the issues mentioned above: (1) during scheduling and passenger allocation, along with the constraints by service providers, passenger preferences and operator preferences should be taken into account; (2) the introduction of a single trusted third party to whom transport offers and requirements are sent would allow mediation between passengers and different operators who are willing to provide transport services in that area. Addressing these issues in a single coherent model offers the opportunity to relax operator restrictions on eligibility by incorporating operator preferences and then explore both the efficient use of limited transport resources, and the integration of passenger preferences in the decision-making process. Existing research in this area (e.g., De Weerdt, van der Krogt, and Witteveen, 2003) tends to focus exclusively on the needs of transport providers.

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In this research we have developed a passenger-centric agent-based FTS platform using argumentation theory. This platform is based on a group of autonomous agents acting on behalf of stakeholders, looking to solve their individual (or collective) transport goals. The platform, which uses autonomous intelligent agents to aid passengers and transport providers to make informed decisions in passenger allocation, provides a virtual transport market place to match existing demand and supply for transport services in rural areas. The approach opens up the opportunity for a much wider breadth of transport suppliers (e.g., shared taxis and liftshare) to become market participants, as well as allowing existing operators to relax their rigid eligibility restrictions by considering operator preferences in the allocation process. This is likely to attract more passengers by increasing the options available to passengers while considering passengers' preferences and improving the level of flexibility in the system.

The remainder of this paper is structured as follows: the following section reviews the state-of-the-art in flexible transport services in the context of rural areas and provides various methods and approaches along with their limitations. This is followed by brief description of a formal argumentation mechanism, and its usefulness in FTS. The paper then describes a passenger-centric FTS platform, which can consider passenger preferences along with operator preferences and limitations in assigning the passenger trips. The usefulness of such a passenger-centric platform for managerial practices is then illustrated. The paper ends with conclusions.

2. Review of FTS in the rural context

Demand-led approaches such as flexible transport services, more formalised lift-giving and community transport schemes are not new concepts; examples of existing approaches include shared taxicabs, shuttle vans, dial-a-ride services and car-clubs (Li and Quadrifoglio, 2010; Mulley, 2010; Mulley and Nelson, 2009). Previous research has confirmed that FTS could be a promising solution for transport problems in remote areas with low population density, where conventional public transport systems are not appropriate and individual travellers have different requirements (Sloman and Hendy, 2008). Moreover, FTS can improve mobility for special users (e.g., the elderly or disabled) because users' requirements are specific, similar and demand density is small; for example, in the case of patient transport, the destination point will invariably be a hospital or a health care centre.

There is considerable practical experience of publically available FTS built up over many years. For example in Scotland as of 2006, there were about 140 (mainly small-scale) schemes in operation (Scottish Executive, 2006). Some examples of these flexible and demand responsive transport schemes in rural areas in Scotland are listed in Table 1.

The majority of the above services are small scale, isolated from each other, allow only advanced booking, often give little or no importance to passenger preferences, and use little or no information and communication technology support (Aberdeenshire being a notable exception). There is an increasing trend towards using taxi operators to provide the services – this offers an already existing vehicle resource as well as a booking capability – and hence offers significant reductions in operating costs. Considering the conditions of public transport in remote areas and geographical conditions (e.g., rurality and widely spread population), further development and improvement of larger-scale FTS is one of the promising solutions to enhance social inclusion, accessibility and mobility (Mulley and Nelson, 2009).

The advent of transport telematics applications over more than 15 years has done much to promote the concept of FTS. The main architectural components of any technology-based FTS (Ambrosino, Logi, and Sassoli, 2001) are the following: (1) the control centre (also known as the Travel Dispatch Centre), (2) customer devices, (3) in-vehicle on-board unit and equipment, and (4) communication devices.

The Travel Dispatch Centre (TDC) acts as a mediator between customers (passengers) and operators and provides a wide range of activities such as trip reservation, travel planning (i.e., optimal route search, vehicle assignment, travel time and delay estimates) and vehicle dispatch and control (Ambrosino et al., 2001; Fu, 2002; Palmer et al., 2004). However, current FTS in rural areas have long been associated with limitations due to available technology, integration, service availability, demand and cost (Shergold and Parkhurst, 2010). This results in TDCs in rural areas often being unable to fulfil certain aspects of passenger requests (e.g., time of travel, journey time and special needs).

The major task of any FTS is balancing demand and supply along with providing the passenger with the desired level of flexibility in choosing a route, travel time, mode of transport, service provider, and payment system. In the literature, different versions of flexible transport systems are reported. The earliest studies concentrated on single vehicle multiple passengers FTS in which a single vehicle is designed for a set of customers whose pick-up and drop-off points are known prior to a trip (Psaraftis, 1980, 1983; Sexton, 1979; Sexton and Bodin, 1985a, 1985b). More recently, studies have explored multiple-vehicle multiple-passenger FTS (see for example Cordeau, 2006; Bent and Van Hentenryck, 2006; Ropke and Pisinger, 2006; Xiang, Chu, and Chen, 2006; Melachrinoudis, Ilhan, and Min, 2007; Parragh, Doerner, and Hartl, 2010; Garaix, Artigues, Feillet, and Josselin, 2010). In flexible transport, different tools and methods are used for mediating between customers and service providers in order to optimise usage of available resources in routing and scheduling a vehicle; several are discussed in the next section.

2.1. Tools and methods used for implementing FTS

A range of optimisation techniques and decision making tools is used for flexible transport systems. The earlier studies used simple dynamic program and integer program optimisation techniques for FTS (Desrosiers, Dumas, and Soumis, 1986; Mitrovi´c-Mini´c, Krishnamurti, and Laporte, 2004; Psaraftis, 1980, 1983, 1995). Recent studies have used some advanced intelligent techniques (such as Tabu search heuristic method and Fuzzy logic) for FTS (Attanasio, Cordeau, Ghiani, and Laporte, 2004; Cordeau and Laporte, 2002; Garaix, Artigues, Feillet, and Josselin, 2011; Garaix et al., 2010; Gupta, Hajiaghayi, Nagarajan, and Ravi, 2007; Nanry and Barnes, 2000). This section provides brief details of these intelligent methods and algorithms.

2.1.1. Tabu search heuristic method

Application of Tabu search method for vehicle routing problems is reported in several studies (Cordeau, Gendreau, and Laporte, 1997; Gendreau, Hertz, and Laporte, 1994). These studies concentrate on routing a single vehicle to multiple destinations. More recently, Nanry and Barnes (2000), Cordeau and Laporte (2003) and Attanasio et al. (2004) have applied this method to the multi-vehicle dial-a-ride problem. Tabu search is a local search optimisation tool, which uses a nearest neighbour algorithm. Users specify their trip requirements: origins and destinations and a time window on their desired departure or arrival time. Transport suppliers aim to minimise vehicle route costs and maximise the number of passengers accommodated. Other constraints relate to vehicle capacity, route, duration, the maximum ride time of any user. A Tabu search method provides good, but not necessarily optimal, solutions for desired trips (either using single vehicle or multiple vehicles) in a network.

2.1.2. A branch-and-cut algorithm

Branch-and-cut is a method of combinatorial optimisation for solving an integer linear programming problem in order to determine a way to achieve the best outcome (such as maximum profit or lowest cost) by satisfying constraints presented as linear equations. Any FTS (e.g., dial-a-ride) problem consists of designing a set of minimum cost vehicle routes satisfying capacity, duration, time window for both

Table 1
Examples of public flexible transport systems in rural Scotland.

Area or council	Scheme	Level of flexibility	Operator(s)	Start date	End date	Source
Aberdeenshire	A2B Dial-a-Bus[a]: Alford; Central Buchan; Fraserburgh; Huntly; Inverurie; Oldmeldrum; Peterhead; Strathdon; Turriff and Westhill	Fully-flexible	Stagecoach Bluebird, local taxi firms and Aberdeenshire Council	2004	Still operating	Scottish Executive (2006) http://www.aberdeenshire.gov.uk/publictransport/a2bdialabus/index.asp
Highland	Network of taxis offering access to work (T2E[b])	Fully-flexible	Local taxi firms	April 2005	Sept 2008	Wright, Nelson, Cooper, and Murphy (2009)
Highland	Dial-a-Bus[c] Aird; Ardross; Black Isle; Dornoch; Gairloch; Nairnshire	Fully-flexible	Local bus and taxi firms	From 1998	Still operating	http://www.highland.gov.uk/
Midlothian	Dial a Journey[d]	Flexible	Local taxi operators	Mar-2003	Mar-2007	Scottish Executive (2006)
East Lothian	Gaberlunzie Bus[e]	Semi-flexible	East Lothian Council and FirstGroup	1999	2001	Scottish Executive (2006)
Dumfries and Galloway	Ring 'n' Ride Services	Semi-flexible	Stagecoach	2002	Still operating	http://www.dumgal.gov.uk
Stirling	1. Balquhidder 2. Fintry 3. Killin and Strathfillan 4. Strathard 5. Trossachs	Semi-flexible	Aberfoyle Coaches	Started in 2008, 2009 and 2010	Still operating	SEStran, 2010
West Lothian	Taxibus services[f]	Semi-flexible area-wide services	Local taxi firms	May-2011	Still operating	http://www.travelinescotland.com/cms/content//WL_Taxibuses.xhtml?lang=en
Strathclyde	My Bus[g]	Semi-flexible area-wide services	Local bus and community transport groups	1996	Still operating	http://www.spt.co.uk/mybus/
Fife	Ring and Ride Kirkcaldy; Levenmouth - (Leven/Buckhaven/Methil/Methilhill, Kennoway, Windygates); Dunfermline (inc Rosyth); Glenrothes	Destination specific and flexible route	Stagecoach	2004	Still operating	http://www.fifedirect.org.uk
Angus	Community Transport Development	Destination specific	Angus Transport Forum	April 2002	2007 April	Eloranta and Masson (2004)

Source: based on Velaga, Nelson, Wright, and Farrington (2012).

[a] A2B dial-a-bus is a demand-responsive fully flexible door-to-door transport service covering specific rural areas in Aberdeenshire, UK.

[b] T2E is a transport to employment scheme in Highland.

[c] Highland Dial-a-Bus is a demand responsive FTS, which is open to all members of the public, operated in a specific time period and defined area.

[d] Due to lack of funding this Dial-a-Journey service was stopped in 2007.

[e] Gaberlunzie Bus aims to connect rural areas to local towns of Haddington and Dunbar. This service was converted to fixed route bus service in 2001, due to high cost per passenger trip (£12).

[f] Taxibus provides public transport to areas at times when no bus service is available.

[g] MyBus is one of the earliest FTS service developed to help people in rural areas with limited or no public transport provision.

travel time and waiting time, passenger pairing, priority and ride time constraints. Cordeau (2006) used a branch-and-cut algorithm for solving multi vehicle dial-a-ride problems. Unlike the Tabu search method, which may not always provide the best optimal solution, the branch-and-cut algorithm can provide optimal solutions to small instances (Cordeau, 2006).

2.1.3. Fuzzy logic

A real-time flexible transport system has to deal with many dynamic features. Passengers have individual preferences over aspects of a journey including its origin, destination, service start time, maximum tolerable extra travel distance and waiting time. Similarly service providers need to design travel routes to carry the maximum number of passengers and profit, and minimise the total travel distance, number of vehicles needed and detour time. Every new passenger request might affect the predesigned route and schedule of the vehicle in the network or demand scheduling of a new vehicle. This decision making process (whether to modify the scheduled route or provide a new vehicle) in real-time involves a logical linguistic process. For example, if the additional waiting time and travel distance for a new request are small then it is preferable to modify the scheduled route. Fuzzy logic is one method that can be used to solve logical conditional statements (i.e., *if* x *then* y) from multiple sources of uncertainty (Chen and Tsai, 2008; Konar, 2005). Teodorovich and Radivojevic (2000) developed a fuzzy inference system to decide whether to modify the schedule route or provide a new vehicle based on additional travel distance and weighting time.

2.1.4. Other approaches

Gendreau, Laporte, and Semet (2001) used a parallel computing approach for a real-time ambulance routing problem. Coslovich, Pesenti, and Ukovich (2006) introduced a two-phase insertion algorithm for a dynamic dial-a-ride problem with time window constraints. Nagarajan and Ravi (2007) developed a poly-logarithmic approximation algorithm for dynamic multi-vehicle FTS problems. Gupta et al. (2007) solved real-time pick-up and drop-off dial-a-ride problems using *k*-Forest method. Garaix et al. (2010) introduced a multi-graph method to design vehicle routes and schedules for a multi-user FTS problem. Berbeglia, Cordeau, and Laporte (2010) proposed a hybrid algorithm, which combines an exact constraint programming algorithm and a Tabu search heuristic, for real-time dynamic dial-a-ride problem.

There are some limitations of existing approaches and methods for implementing FTS in rural areas. These include the following:

1. Most of the methods schedule and allocate the demand to the supply (fleet of vehicles) in an optimal fashion which maximises total revenue (or minimises subsidy required).
2. None of the approaches consider hierarchy of passengers in allocation (i.e., high priority to elderly and disabled).
3. They consider only a fleet of vehicles from a single operator.
4. None of these approaches consider passengers, operators and transport authorities perspective concurrently.
5. Most methods are developed for the generic dial-a-ride problem; not for a range of service types with differing requirements and constraints. They may not be suitable in the rural context, where there is irregular demand and passengers with more specific constraints.
6. Most cases concentrate on scheduling vehicles on optimal routes and the maximum allocation of passengers thereby increasing profit for operators (or minimising subsidy required).
7. There are no visualisation techniques (map view) on how the optimal decisions are made.
8. Passenger requirements/preferences are often ignored.

It can be inferred from the above literature review that most of the existing approaches for FTS often ignore the passengers' perspective, concentrating either on better utilisation of resources (vehicle fleet), minimising travel time or maximising vehicle occupancy. Existing approaches do not consider the prioritisation of passengers in trip allocation, that is, selecting a passenger from a set of two or more potential passengers if a single seat is available on a journey. Current practice is based on a first come first served basis. Where prioritisation is important, the services tend to set strict eligibility criteria which eliminate most of the population from using the service. However, by considering operator preferences in the allocation process, strict eligibilty criteria can be relaxed enabling a wider range of services to be offered to the wider public when priority passengers do not fill the seats. This becomes particularly beneficial in rural areas where service providers are fewer in number and fleet size is typically smaller. To deal with dispersed demand in rural areas, co-ordination and integration of diverse services and different operators are often necessary.

The provision and successful implementation of flexible transport solutions in rural areas introduce unique requirements. In the remainder of this paper we argue that the following are required: (1) a passenger centric scheduling/allocation approach in which passenger preferences and alternative options are considered during scheduling or allocation of passengers to the vehicle supply; (2) a virtual transport market place where different services are integrated and all operators co-ordinate with each other; and (3) a single trusted third party to whom transport offers and requirements are sent, and which solves the allocation problem by considering both passenger and operator constraints and requirements.

To fulfil some of these requirements, we propose an argumentation-based passenger-centric Flexible Integrated Transport Systems (FITS) platform. The following section outlines computational argumentation and its use in flexible transport systems.

3. Agents and argumentation

Computational argumentation is a relatively new discipline within artificial intelligence, allowing the representation of, and reasoning over, inconsistent knowledge (Rahwan and Simari, 2009; Reed and Norman, 2004). Pieces of knowledge are organised into arguments, which are reasoning steps (not necessarily atomic) leading to a conclusion from a set of premises. Arguments are required to comply with minimality and inner consistency, among other possible restrictions. In the literature, abstract argumentation frameworks are graphs of arguments upon which an evaluation is performed to extract the set of warranted arguments (Dung, 1995), i.e., arguments that can be believed in despite having reasons in opposition. The objective of the research reported in this paper is the development of an argumentation-based FTS tool built upon a multi-agent system (Wooldridge, 2009). Each passenger will have an associated agent, in charge of producing potential journeys, triggered by trip requests. These potential journeys would be prioritised following the passenger's preferences, something argumentation is very suitable for. Furthermore, we also incorporate transport operators into the equation, each of which also has an agent associated to them. The task of these agents is to validate certain passengers-to-vehicles allocations according to the operators' usage conditions and any preferences they may have. Once both types of agents “opinions” on these plausible journeys are gathered, an argumentation process decides which options are viable, and then leaves the final decision to a voting mechanism. The system characteristics will be addressed in the following section. We contend that an argumentation system is suitable to address the problem of passenger's choice, since:

- it captures preferences in a natural way
- it provides automatic reasoning capabilities
- it is suitable to provide knowledge visualisation
- reasoning and visualisation technique in passenger allocation provides an explanation to each allocation
- users' goals and utilisation of resources tend to be conflicting (for example, limited space and fares)

Once we have defined how to build arguments, for any given pair of arguments, preferences indicate which one is the prevailing argument. That is, either one argument defeats the other or they are involved in a mutual defeat. In the FITS domain, arguments are possible journeys, which are under conflict for each passenger, and unrelated with other passengers' possible journeys. Only seat availability brings about inter-passenger conflicts. However, these conflicts do not qualify as such in the traditional usage in argumentation theory, as they arise only after the arguments at issue were warranted. In other words, arguments would only acquire resources once they are deemed acceptable. Current argumentation systems do not possess this characteristic. Therefore, a new theoretical element has to be incorporated to the framework in order to deal with resource boundedness (Rotstein, Oren, and Norman, 2011). A resource-bounded argumentation framework, or RAF, is a traditional framework extended with a set of resource bounds (or "RB set") containing pairs (Args, Bound), where Args is a set of arguments bounded by the limitation defined by Bound. For instance the RB set $\{(\{j_1^{p1}, j_1^{p2}\}, v_1\,(1))\}$ declares that two journeys (j_1^{p1} for passenger 1 and j_1^{p2} for passenger 2) are bounded by the only seat available in vehicle v_1. This bound is violated if and only if both arguments are warranted.

Another advantage of argumentation-based systems is that they can be easily visualised. A traditional argumentation framework could be thought as a digraph, where nodes are arguments and edges indicate defeat relations between pairs of arguments. In the RAF, a third element is added: an extra node indicating the amount of available tokens of a given resource (e.g., regular seats, seats for wheelchair users). After the framework is evaluated to discover which arguments are warranted, the output can be displayed by simply colouring nodes. Such a visualisation tool is useful to build explanations backing the system's output. On the development side, an explanation is a debugging tool that allows us to check whether the system is behaving correctly; for instance, we must ensure that at most one journey is assigned to each passenger. This can be easily visualised through the argumentation graph. An example of such an argumentation graph is shown in Fig. 1. Here individual boxes represent each passenger and his or her transport option (e.g., travel time, distance, cost) and order of passenger's preferences (e.g., number of changes, waiting time and cost); and the colour of the box indicates recommended solution (for example in this case green boxes are the recommended trips). The arrow connection between each box indicates the defeat relationship.

So far we have not mentioned how to evaluate the graph in order to obtain the set of warranted arguments, i.e., the framework's semantics. We will provide a notion of it, without getting into details. Many argumentation semantics have been defined in the literature, and all of them comply with the basic condition of conflict freeness. The simplest semantics is the grounded, which specifies that all undefeated arguments are warranted, and those defended (defeating a defeater) by warranted arguments, whilst keeping conflict freeness, are also warranted. However, in the presence of loops (i.e., mutual defeats) the grounded semantics is, in many cases, unsuitable. Consider the case of a framework with two arguments A and B involved in a mutual defeat. In our application domain that would mean two equivalent (i.e., the passenger does not prefer one over the other) possible journeys for the same passenger. The grounded semantics would warrant neither; it would return the empty set. There are, however, other semantics that would be suitable for such a scenario. We will not discuss this topic any further, as it is out of the scope of this paper, but will just introduce the one we have chosen: the preferred semantics. Informally, this approach warrants any maximal, conflict-free subset of arguments such that it defends itself from external attacks. These semantics could return multiple, alternative outputs. In the previous example, both {A} and {B} are plausible outputs, as each set defends itself from external attacks, yielding the desired behaviour for our application domain. For more details regarding argumentation semantics the reader may refer to Baroni and Giacomin (2007).

4. The FITS platform

The proposed FITS platform is a passenger-centric journey-allocation system that also considers vehicles' usage conditions imposed by transport operators. Although the main task of this system is to get passengers from origin to destination by allocating them into vehicles, scheduling is not the problem we address in this work. A number of other platforms (e.g., from Trapeze or Mobisoft) have been extensively developed to schedule journeys, and the FITS

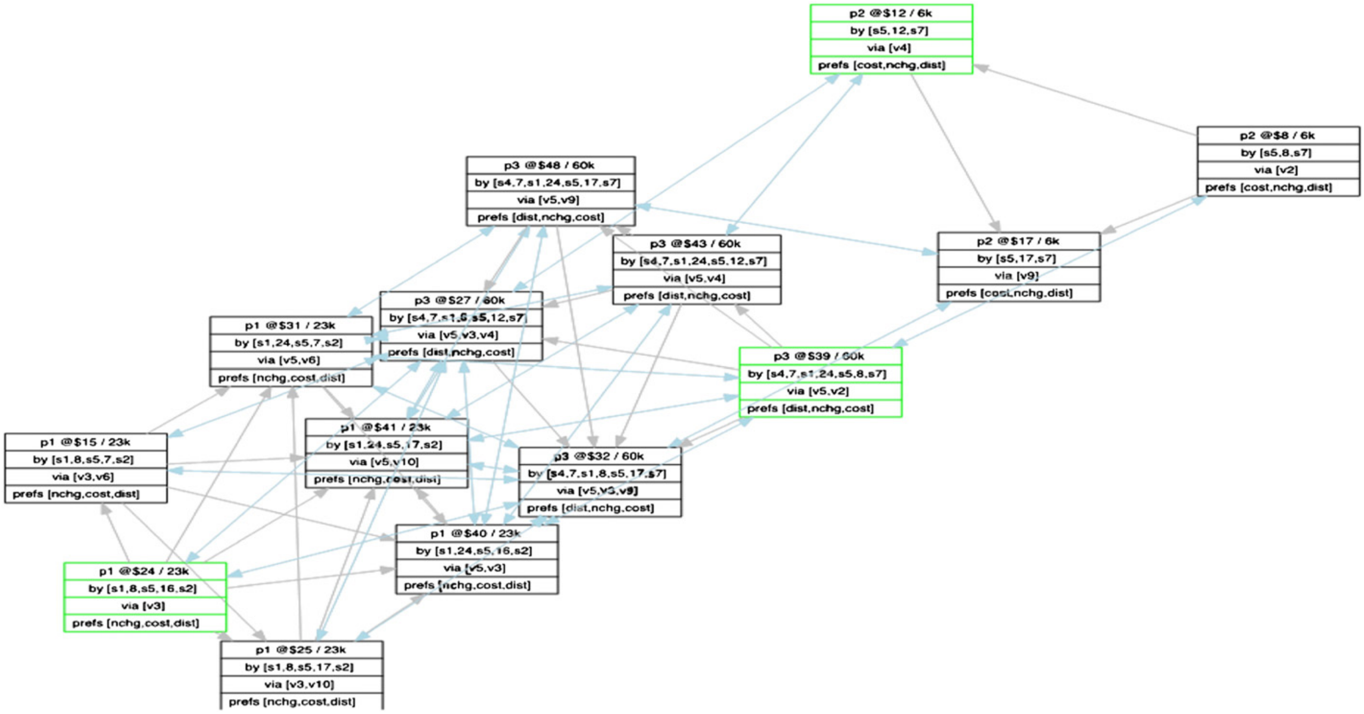

Fig. 1. Argumentation graph.

platform would be complement of this mechanism, the main objective being to increase fairness across three axes: passengers, operators, passengers-operators. Fair treatment of passengers means that no passenger is given priority unless required by regulation or stipulations in an operator's contract, e.g., disabled/elderly passengers. Fair treatment of operators would be achieved by handing them the validation of passengers' allocation. Fairness between passengers and operators refers to not denying passengers their most convenient journeys whilst offering operators the opportunity to validate these potential allocations. We will deepen the discussion on the topic of fairness after presenting a thorough description of the platform.

Operationally, given a map and a set of available vehicles, the system computes a certain number of possible journeys for each passenger. Then, a certain number of passengers-to-vehicles allocations is computed, each of which is compliant with vehicle usage conditions. Each journey involves the creation of a route compliant with the operators' requirements. We contend that a globally fair solution is provided by taking votes from each passenger regarding which allocations they prefer. Next we describe inputs, outputs, and the internal decision-making mechanism implemented in the FITS platform.

4.1. Inputs

4.1.1. Passengers

The system operates over a batch of passengers admitted within a given time window. Each passenger provides the following information:

- origin
- destination
- travel time window
- order of preference among: travel cost, number of changes and journey length

Note that the first three items are requirements; i.e., conditions that must be fulfilled for a journey to be a candidate.

4.1.2. Operators

Their role in the system involves providing vehicles along with their usage conditions. These requirements could be collective or on a per-vehicle basis. There are several aspects that could determine whether an operator's vehicles are put to good use, for instance, setting a minimum total profit. Other usage conditions include time restrictions (such as “vehicle operates within a time window,” “vehicle operates for no longer than a certain time”), mileage restrictions (either minimum or maximum), occupancy (possibly enforced by the local authority) and passenger preference (prioritising certain types of passenger based on regulation or stipulations in their operating contract). Operators may specify a combination of conditions. Note that there are two types of usage conditions: individual (applicable to single vehicles, e.g., vehicle occupancy) and collective (applicable to the whole pool, e.g., total revenue optimisation through cost saving).

4.1.3. Map

This provides the road layout, including stops and distances. Other data, such as road conditions, weather and traffic could be incorporated to enhance decision making.

4.2. Outputs

4.2.1. Passengers

At most one journey per passenger, as some could have no plausible options. Further enhancements to the platform could include to relax a passenger's preferences whenever they are left with no journey. This should be designed carefully, as new options may disrupt the whole decision-making scenario. An alternative solution would be to provide passengers excluded from a solution with explanations and options that do not completely meet their requirements. Therefore, they still have the option to decide and get on vehicles that will be running on the routes designed by the system.

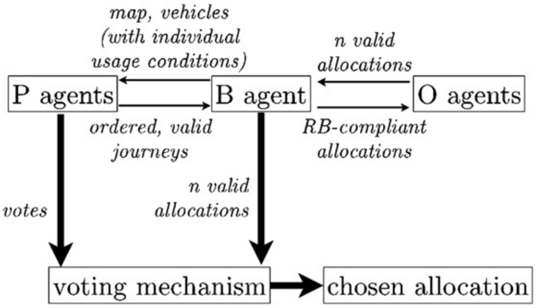

Fig. 2. FITS platform.

4.2.2. Operators

At most one journey per vehicle, as some could have no plausible options. As in the case of the passengers, whenever an operator's usage conditions have not been fulfilled, a log or explanation should be recorded and provided to them in a suitable format. In this way, operators could potentially correct their usage conditions policies, adjusting to the demand.

4.3. Reasoning

The multi-agent system will include three types of agents: those representing passengers (“P agents”), those acting on behalf of operators (“O agents”), and one agent acting as the brokering entity (“B agent”).

Next we describe the distributed reasoning system, illustrated in Fig. 2.

4.3.1. P agents sub-system

The system (i.e., the B agent) provides each P agent with the map and pool of vehicles along with their individual usage conditions. P agents have a built-in scheduler, utilised to generate a certain number of plausible journeys for the corresponding passenger, that is, journeys that comply with both the passenger's requirements and the involved vehicles' individual usage conditions. These plausible journeys are then ordered according to the passenger's preferences. Note that calculating all plausible journeys would be computationally prohibitive, thus an upper bound is required.

4.3.2. Brokering sub-system (B agent)

This sub-system gathers all the P agent's ordered plausible journeys and composes a certain number of allocations, i.e., an assignment of passengers to sequences of vehicles. This is done by virtue of a resource-bounded argumentation framework (RAF) (see Section 3 above), where journeys are arguments, and preferences are defeats.[1] The only kind of conflict involving different passengers comes from resource bounds, which are likely to arise when considering the allocation of different passengers to the same available vehicle. This will be exemplified later in this section. Passengers' journeys are thus combined into allocations, which are checked against resource bounds by virtue of the underlying RAF. As mentioned above, an upper bound to the number of allocations has to be imposed, as it would be impossible to compute them all exhaustively. These are then passed on to the O agents.

4.3.3. O agents sub-system

Allocations are streamed to the O agents in order for them to validate them with respect to each operator's collective usage conditions. If an allocation does not involve vehicles from a certain operator, that

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[1] Note that defeats only involve arguments from the same passenger.

operator automatically validates it. Hence, an allocation is invalid only when at least one of the involved operators' collective usage conditions is not satisfied.

4.3.4. Decision making by voting

This interaction between the B agent, the P agents and the O agents yields a set of non-resource-bounded operator-validated candidate allocations. The final step is to choose the globally preferred allocation from this set. For this, we use a variation of the Borda voting mechanism (Wooldridge, 2009): each of the P agents votes by assigning a rating to each candidate allocation, and the allocation with the best rating wins.

Each P agent assigns a rating to every allocation in the form of an ordered triple representing the individual ratings for each of their preference items. For instance, if the preference order is "cost of fare > length > number of changes" and the best possible journey has a cost of £10, a length of 10 km, and 1 vehicle change, then the rating for a journey with a cost of £15, a length of 12 km, and 1 vehicle change would be (1.5, 1.2, 1). The rating for the best journey would be (1, 1, 1). Ratings for cost and length are computed through simple division (as they will never amount to zero), but for number of changes we have chosen to divide by the number of vehicles needed for that journey (as number of changes could be sometimes zero). Other voting or social choice systems could be used; different approaches will yield different results. We have chosen the Borda mechanism because it has some interesting properties, such as "rotational symmetry"; that is, it cancels out opposing votes.

We do not give O agents the possibility to vote, as the Borda system tends to achieve a general consensus and operators would bias it towards their own interests. This would be unrealistic, as in any provision of services, consumers decide over the available offers. Operators have the option of validating allocations; after that, it is up to passengers' consensus to decide over the selected allocation.

Once all the votes have been gathered, the triples are summed up component by component. For example, if we have 2 passengers voting for a given allocation, summing their votes (x_1, y_1, z_1) and (x_2, y_2, z_2) would yield $(x_1+x_2,\ y_1+y_2,\ z_1+z_2)$. Thus, we attempt to abstract away from the difference in passengers preferences by assigning absolute values into each of the categories. Since these results are ordered triples, we sort them according to the first component; if the first components are equal, then we evaluate the second component, and so on with the third component. Next we present a complete example for the FITS platform.

4.4. Worked example

Let us assume two passengers, Rob and Tom, with the following characteristics:

- Rob
  - o Origin: a; destination: c
  - o Time window: from 8.00 to 14.00
  - o Preferences: cost > length > number of changes
- Tom
  - o Origin: a; destination: d
  - o Time window: from 10.00 to 13.00
  - ○ Preferences: number of changes > cost > length

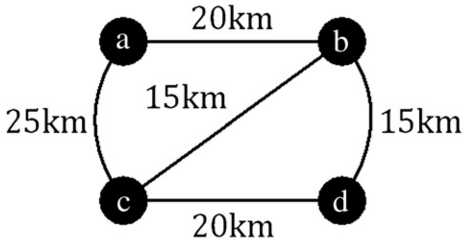

Fig. 3. Example.

Considering the following map:

Consider the following operators and vehicles:

- op1 provides vehicles v1 and v2, available from 10.00 to 16.00, charging £0.25 per kilometre, refusing a total revenue of less than £10, and:
  - ○ Vehicle v1 travels through roads a–b and c–a
  - ○ Vehicle v2 travels through roads b–c and c–d
- op2 provides vehicle v3, available from 8.00 to 18.00, charging £0.35 per kilometre, travelling through any roads as long as travel distance is more than 20 km.

Given the map and pool of available vehicles, we will assume that up to three potential journeys are computed by the built-in scheduler in Rob's and Tom's P agents (see Fig. 3). From now on, for the sake of simplicity, we will abstract away from time windows, assuming that any combination of these journeys (i.e., allocations) is compliant with them.

Table 1
Passenger journeys.

Passenger	Journey	Fare cost (£)	Length
Rob	j1: [a–v1–c]	6.25	25 km
	j2: [a–v1–b–v2–c]	8.75	35 km
	j3: [a–v3–c]	8.75	25 km
Tom	j4: [a–v1–b–v2–c–v2–d]	13.75	55 km
	j5: [a–v1–c–v2–d]	11.25	45 km
	j6: [a–v3–b–v3–d]	12.25	35 km

The output of the corresponding P agents is:

- Rob: j1 > j3 > j2
- Tom: j6 > j5 > j4

These journeys are sent to the B agent, which creates all the potential allocations. Let us assume that the system is capable of computing up to 6 allocations, which are as follows:

Table 2
Operator revenue.

Allocation	Revenue (op1)	Revenue (op2)
a1: (j1, j4)	£20	£0
a2: (j1, j5)	£17.50	£0
a3: (j2, j4)	£22.50	£0
a4: (j2, j6)	£8.75	£12.25
a5: (j3, j5)	£11.25	£11.25
a6: (j3, j6)	£0	£21

When allocations are checked against resource boundedness through the RAF, we have that a1 utilises vehicle v1 for two different routes, and thus the allocation is rejected. A similar situation occurs with a6 and vehicle v3; therefore a6 is also rejected.

From the remaining allocations, the only one rejected by an O agent is a4, as it violates op1's total revenue maximisation. The rest of the allocations are valid and one must be chosen to finally inform the passengers about their journeys. Next, we present a table including both passengers' votes. Recall that Rob's preference order is cost, length and number of changes, whereas Tom's is number of changes, cost, and length.

Table 3
Voting process.

Allocation	Rob	Tom	Total
a2	(1,1,1)	(1, 1, 1)	(2, 2, 2)
a3	(1.4, 1.4, 2)	(1, 1.22, 1.22)	(2.4, 2.52, 3.22)
a5	(1.4, 1, 1)	(1, 1, 1)	(2.4, 2, 2)

The final allocation ordering is: a2 > a5 > a3.

Note that the best possible allocation would have been the one containing journeys j1 and j6, but the system was not able to compute it. This is a normal limitation that is also present in existing scheduling systems: due to the enormous number of possible combinations, there is no way to ensure a scheduler will yield the best journeys. Analogously, there is also no way for the FITS platform to always find the best allocations, as it would require an exhaustive search. Heuristics could be used as an attempt to get "good" allocations, e.g., combining the best individual journeys first, according to each passenger's preferences, which is what the current implementation does.

Regarding fairness, in the example, fairness among operators is achieved by giving them the possibility of expressing their usage conditions and creating allocations independently from the benefits that they could imply to individual operators. Similarly, passengers were given equal opportunity to vote over each allocation, and the winning allocation is elected by consensus. The participation of both sides is balanced by letting operators choose the characteristics of the journeys they offer, to then let passengers to vote over these options.

As mentioned above, problems associated with the provision of flexible transport in rural areas are challenging different (e.g., a small number of service providers). In order to enhance the provision of FTS in rural areas, in the following section, we have also recommended some implications for future managerial practice of flexible transport in rural areas.

5. Implications for managerial practice of rural FTS

As discussed in Section 2, although FTS offers potential to meet the requirements of travellers in rural areas there are certain issues involved in development and implementation. These include: (1) level of demand is uncertain; (2) a smaller number of service providers; (3) individuals with a wide variety of requirements; and (4) a frequent need to deal with dispersed demand over a large area.

In order to cope with the above difficulties, we have identified a set of managerial practices and recommendations to enhance the provision of FTS in rural areas. These include the following:

1. Passenger-centric allocation: Generally, research on FTS scheduling focuses exclusively on maximum benefit to operators; passengers are included in the schedule on a first-come first-served basis. This approach often ignores passenger preferences. Therefore a passenger centric allocation and scheduling approach, in which passengers preferences are given importance along with operators' constraints, whilst also fulfilling transport authorities/government rules and policy (e.g., give more importance to elderly during trip allocation), could be more beneficial in rural areas.
2. Facilitating collaboration among operators: It is identified that the number of service providers is fewer in rural areas; therefore individual services need to be integrated and all operators should be encouraged to co-ordinate with each other and to relax absolute restrictions on eligibility by defining preferences for the passengers they can carry. This might be possible by developing a regional level virtual market place (i.e., a single trusted third party) which mediates between passengers and a set of operators and service providers.
3. Understanding the market better: The market and transport demand in rural areas are very volatile. For example an event taking place in a village/key centre will generate higher transport demand for that village. Therefore it is required to better understand the requirements of the transport market and demand in rural areas.
4. Service design: The requirements for each service vary; when developing flexible transport services it is required to consider specific requirements of service.

5.1. Contributions to scholarly knowledge

In this research, we aim to develop a platform for passenger-centric flexible transport services. In Section 2, limitations with the existing approaches and methods for implementing FTS in rural areas are identified. The work presented in this paper could help to overcome some the existing limitations; these include the following:

(1) considering passenger requirements/preferences and providing a hierarchy of passengers in allocation
(2) providing visualisation techniques (map view) on how the optimal decisions are made
(3) considering passengers, operators and transport authorities perspective concurrently

Moreover, this platform supports some of the above managerial practices and recommendations. Previous research on scheduling and passenger allocation mainly concentrates on maximising passenger capacity and minimising trip length thereby increasing profit for operators (or reducing subsidy requirements). The platform developed in this research gives priority to the passengers' preferences and takes account of operators' constraints. Moreover the developed platform acts as an agent-based single trusted third party which works in an integrated manner by allowing all operators to co-ordinate with each other and integrates different services. The approach developed in this paper also offers the potential to up-scale FTS and move beyond the proliferation of small scale schemes by enabling a wider base of transport providers to participate.

6. Limitations

As for platform enhancements, one could consider adding weather, traffic and road conditions to the map provided to the P agents. This extra information would help the passengers to make more informed decisions, in the sense that they would be more aware about the possible delays and journey experience in general.

In addition to this, as mentioned in Section 4.3, we will try to provide alternatives for those passengers whose requirements were not met, and thus were left with no options. This would involve relaxing requirements and shuffling preferences, incrementally, in order to allow for more options. Passengers can still refuse to take these alternatives. Note that the system would only recognise that a passenger has no alternatives only when the allocation for the current batch has been already computed. Hence, these new alternatives will either have to be adjusted to the current allocation, or a completely new allocation should be computed.

Whenever an operator ends up with their vehicles unused, a report could be elaborated from the result of the argumentation process, showing the usage conditions that were not complied with by the current allocation. In this way, if necessary, they can adjust their requirements to satisfy past unmet demand.

In this research we demonstrated the platform using a worked example. One could further examine the performance of existing platforms and the platform developed in this study using different practical scenarios drawn from real-world synthetic (but realistic) case studies.

7. Summary and conclusions

This paper has introduced the FITS platform, a passenger-centric journey allocation system that considers not only passenger requirements, but also the constraints imposed on vehicle usage by transport operators. The FITS platform is built on top of a multi-agent system in which argumentation is used to find an optimal, or at least "good enough" fit between passengers, vehicles and journeys. In Section 2 we identified several existing techniques for implementing flexible transportation in various contexts. As shown, while each addresses its own problem niche, none are capable of balancing the diverse needs of the various stakeholders in the transport ecosystem, meaning that FITS brings new capabilities to the transportation marketplace.

FTS is particularly applicable to rural areas, where there is often little, if any availability of conventional transportation services. FITS represents a first attempt at addressing the requirements of this space, and we have proposed several directions of future work to enhance our base platform (in Section 6), and to better operate in the rural transport domain. Many of these challenges are technical in nature, for example requiring us to further enhance our representation formalism to better capture passenger requirements. Once addressed, we intend to deploy FITS to provide decision support services to several FTS providers, allowing us to evaluate FITS in the real world.

The developed platform could act as an additional layer on existing scheduling software (e.g., Trapeze or Mobisoft), which have been extensively developed to schedule journeys. With the existing scheduling software/systems there are certain constraints (for example, they could not consider passenger preferences while scheduling journeys and logical hierarchy of passengers during allocation is not available); some of these constraints are answered in this paper. The developed FITS platform could be useful to FTS service providers, who use conventional scheduling software for trip allocation, to enhance their system and make it more passenger centric.

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