Smart-agent system for flexible, personalised transport service

Godwill Vegah[1]*, Usman Wajid*[2]*, Bamidele Adebisi*[3]

[1]*Adaptive E-Learn Systems (ADES), Innospace, Manchester Metropolitan University, Manchester, UK*
[2]*Information Catalyst, Manchester, UK*
[3]*Electrical and Electronics Engineering Department, Manchester Metropolitan University, Manchester, UK*
E-mail: godwill.vegah@gmail.com

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Abstract: Various studies are on-going, for smart-technology and the Internet of things, on a range of issues, to optimist services in the urban transport sector. A key challenge in urban-transport sustainability is shifting commuting transport demands to cost-effective modes, given the capacity of transport operators in cities are usually under pressure; hence, the need for innovative approaches. This research focus on smart-agent system, for flexible, personalised transport service (SAPS), addressing on-time access and multiple-provider-resource management, for personalise commuting services; and to minimise carbon emission footprints. It applies intelligent agent-support algorithms in managing urban-transport resources. SAPS architecture utilises intelligent agents for collaboration strategies in negotiating personalised-transport-resource requirements, with multiple-urban-transport providers. On the basis of commuter requirements, which are updatable in real time, the system devises adaptive-routing plans, formalising provider–commuter service plans, between commuters and transport services providers; hence, delivering customisable urban-transport services. Results and functional prototype of the smart-urban-transport agent system demonstrates effective personalised urban-transport services for 'green commuting'. The approach optimises urban-transport services for commuters and providers; significantly cuts down CO_2 emission footprints, thus providing eco-friendly urban-mobility services and improving management of commuting infrastructure.

1 Introduction

Various attempts in developing innovative urban-transport systems to manage increasing diversified requirements of commuters are on-going. Approaches to improve local public transport infrastructure include specialised 'city-council-contacting transport services', aimed at reducing CO_2 emissions [1]; encouraging 'car-sharing modes', to reduce carbon footprints [2]. Detailed analysis shows that most city/urban car journeys (55%) are <5 miles, many of which are walkable, made by bike or public transport.

One of the key challenges of urban-transport sustainability is to shift commuting demands to cost-effective modes, given that the capacity of transport operators/services, in cities are usually under pressure; hence, the need for new/additional approaches. This research focuses on smart-agent system, for flexible, personalised transport service (SAPS).

It examines the key issue of commuter requirements in cities/urban areas (the demand), to maximise the utility of existing and planned infrastructure, by distributing demand across a range of transportation modes, routes and time; allowing city transport operators to do more with less. SAPS takes a holistic response, examining both the supply (physical commuting modes/existing e-services) and the demand for mobility services, by:

a) Actively managing city transportation capacity over time to make the most and efficient use of existing physical infrastructure (i.e. city transport/mobility resources) for operational efficiency.
b) Processing commuter requirements and distributing reliable information for commuters, on 'best-routes' and 'best-available-transport resources', relative costs and benefits of 'on-time' commuting options; hence, personalising commuting services and promoting behaviour change.

The later approaches help to reduce peak demand for travel for any single mode (car, train, coach, bike, bus and urban taxi) and commuting routes (CORTs); as well as distribute the overall demand over time and across modes.

Existing work in urban-transport services [3] reveals that smart transport IoT data ecosystem (STRIDE) [20], models for optimising dynamic urban mobility (MODUM) and private services such as UBER [28, 35] (an example urban-transport systems) have not only infrastructural problems, but also 'system design issues', and typically difficult to personalise. Limitations or restrictions inherent in the system range from poor routing facilities (leading to congestions and high CO_2 emissions) to excessive delays and non-availability of commuting services, in extreme cases. In this context, SAPS addresses the needs of personalised and provide an adaptable transport-services system for commuters with wide ranging requirements.

This research investigates and develops suitable e-infrastructure to improve and simplify the commuters' experience, in cities and urban areas; reduce carbon emission footprints; and optimise and personalise management of local commuting services.

This paper presents SAPSs, applying emerging technologies and tools, in innovative and adaptable transport-services; addressing 'personalised commuter-routing issues' for urban-transport services. The objectives, focused on flexible personalised urban-transport-services, are to: (i) generate and monitor commuter-transport-service options that are based on commuter-requirement and urban-transport-provider capabilities; (ii) enable commuters make best use of commuting resources from multiple providers; and (iii) provide flexible, customisable urban-transport system, applying intelligent software agent 'reasoning', 'planning' and 'collaboration' capabilities.

The rest of this paper is organised as follows: Section 2 examines current and existing urban-transport-services issues in the urban-transport sector; identifies and highlights issues of existing transport systems including current limitations of urban-transport options, inefficient use of resources and reduction of CO_2 emissions. Section 3 analyses existing solutions to urban-transport management and the shortfalls, whereas Section 4 details the design and implementation of SAPS artefact. Section 5 presents the results of SAPS implementation. Section 6 highlights SAPS innovation and contribution to urban-transport-resource management. Sections 7 and 8 summarise results of this research and outlines future work.

2 STRIDE project

The applications of Internet of things (IoT) and intelligent agents in addressing commuting and urban-transport challenges are currently few and limited. A review of existing approaches demonstrates the need for innovative transport management systems, to address urban and inter-city commuting services.

The STRIDE project [3] allows the transport and logistics sector to exploit rich and complex data assets, intelligently, for efficient use of transport infrastructure. STRIDE creates an IoT cluster (of East England region), which provides a critical mass of diverse transport data including historical and real-time data collected from sensors of various devices; working with stakeholders to ensure broad dissemination and uptake of the project results. STRIDE provides a focal point for the development of smart transport applications and business process improvements, helping determine commercial conditions that must exist for such ecosystem to thrive and work with stakeholders to ensure broad dissemination and uptake of project outputs.

STRIDE accumulates useful data for the transport sector as a whole; however, it neither addresses specific modes of transportation nor suggests useful ways of applying and/or analysing the regional transport system data. A related project, i-MOVE, creates an IoT ecosystem for transport focusing on urban 'congestion corridors' to provide new services and applications from a scalable and interoperable information hub. i-MOVE uses data from local traffic systems, mobile cells, the highways agency, social media and transport services to create a Transport Applications Store, where new products and business models will be developed for freight, public and private transport. By addressing congestion and disruption, the value proposition for the ecosystem seeks to enhance and create a sustainable facility and services. The service focuses on providing access to 'geographic ports' and private vehicle routes.

The IoT research work helps the transport, logistics sector exploit rich and complex data asset base, more intelligently, leading to more efficient and efficacious use of transport infrastructure. The challenge is to create an environment where data providers have incentives to share data and application, with service providers in suitable and accessible formats.

2.1 Private and public transport-service systems

With increasing population density in urban cities, there is increasing need for 'smart public transport services that are flexible and cost-effective to manage the needs of commuters. The online 'urban-transport booking system', UBER [4], or 'smart taxis services', attempts to a 'smart-booking system' for transportation in urban environments. The system processes user details (name, mobile number, payment details – credit/debit card numbers and promo codes); locates user location from the customer phone global positioning system; assigns the nearest resource (taxi/driver resources); and offers a quote based on user pick-up and drop-off location.

The UBER system has drawback in that: (a) there are no customer negotiation options; (b) the system is not interactive with clients; (c) prone to 'potential-overcharge of the client', whether or not services rendered, are satisfactory; and has limited or no processing of commuter feedback.

Similar and relevant urban-transport types to UBER, with shared-service options [5], demand up-front payments, but with limited or no 'real-time journey planning' provisions for commuters.

Government city council bicycle and car sharing service [6] in major cities, provide 'grab and go' bikes commuting services, especially for 'last-mile' connections as well as 'grab and go' private car schemes, as alternative 'linking modes' of travel. City and urban taxi booking service [5, 7] provides another choice of 'transport fuel-type management', at any place or time; and collated data used to inform taxi fleet management and other public transit services; hence, to an extent informs urban-transport infrastructure planning and public policy.

Current urban-transport shared services [5–7] use data to plan future operations, as a mechanism to influence commuter behaviour, and plan future infrastructure and services, based on demand, making use of command control centre services (CCCSs). The Minnesota Urban Partnership Agreement [8], for example, manages travel expectations and route plans, applying a 'variable message system'; and CCCS apply 'predictive analysis' and 'prevailing conditions' to manage traffic and 'travel in real-time', based on 'past travel patterns'.

In summary, private and public urban-transport services share a common problem of flexibility in providing urban transportation service integration options, for optimised commuting journeys not only just for efficient urban-commuting, but also for effective management of CO_2 emissions.

2.2 MODUM transport systems

MODUM project [2] addresses environmental footprint in the transport sector, using a '*pro-active demand-responsive management of traffic' approach*. This project aimed at enabling energy-efficient multi-modal transport choices, accommodates dynamic variations, minimising environmental impact, to improve the quality of life in urban environments. MODUM proposed multi-modal route guidance to commuters, to reduce journey times and CO_2 emissions. A key contribution of the project was the development of a software agent system-based model for the control and balancing of the overall traffic-flow within a city. This model built on the Crosswork and SUDDEN projects [3]. In addition, MODUM contributed in the area of user evaluation, allowing the potential social acceptability of the proposed social transport models considered during its development. MODUM does not however address multi-provider collaboration issues, as well as personalised usage or flexibility in utilising urban-transport services [34].

Other relevant work [21, 31, 32] on intelligent transport systems included the proposed design of 'high-level functionality', comprised of 'sensor network of vehicles' in designated vicinity, and 'exchanging traffic-related information'; management of cognitive functionality placed inside vehicles for inferring knowledge and experience; as well as management of cognitive functionality in the overall transportation infrastructure. The functionalities of the later, mainly issued directives to the drivers and overall valuable context-handling information, to transportation infrastructure [33, 34].

SAPS, discussed in the following section, extends the commuter and provider aspects of MODUM and addresses 'multi-provider collaboration issues'; as well as flexible, personalised utility services, for urban transport services.

3 Smart-agent system for flexible, personalised transport system

SAPS research focuses on 'smart-technology for personalised urban-transport services. Fig. 1*a* shows the block diagram of the (i) research process and (ii) SAPS development phases illustrating details of the SAPS approach from investigating commuting issues and challenges, to a proposed solution of dynamic urban agent-support transport services. Provider routing plans [provider-resource-service plan (PRS-PLAN)] and commuter-routing plans [commuter-routing service plan (CRS-PLAN)] are formalised with the urban-transport-service system in the 'knowledge building' and 'knowledge using' cycle. Existing legacy transport-service resources [26, 27] are accessed by SAPS smart-agents for data evaluation, transformation, processing and presentation, in suitable formats, to commuters on various devices and media; addressing commuter requirements; and hence providing urban commuting options. Fig. 1*b* details the SAPS infrastructure – its users and user interface agents (UIAs) and interactions with commuter-routing

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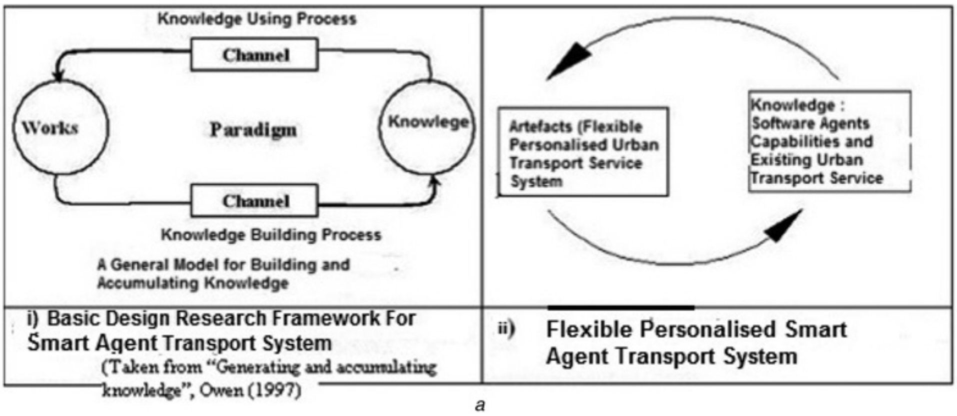

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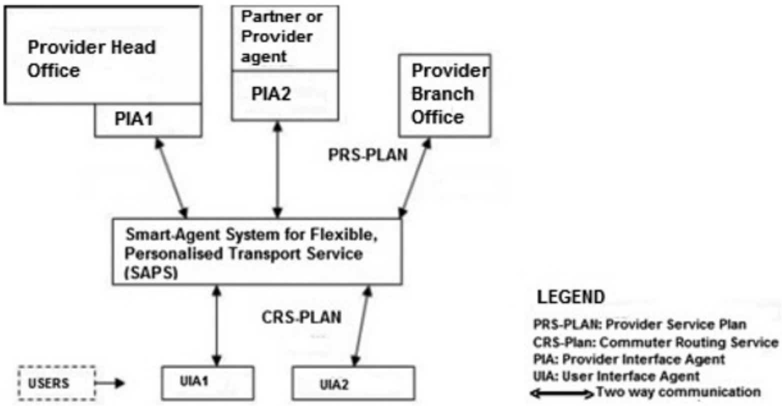

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Fig. 1 *Block diagram overview SAPS system*
a Block diagram of SAPS processes
b Overview of SAPS

plans, transport providers routing plans and provider IAs (PIAs). Their interactions are shown with arrows.

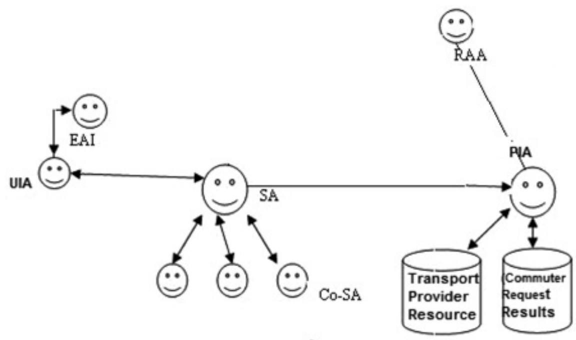
SAPS employ smart-agents underpinned by artificial intelligence planning techniques [10, 11] to address urban-transport issues of 'on-time access', 'commuting-resource availability' and 'environmental awareness or CO_2 emissions'. It supports commuter, urban-transport services providers and urban-transport-service agents by: (i) negotiating commuter requirements with multiple providers and (ii) matching commuter requirements with multiple-provider resources, for effective services.

Intelligent capabilities of software agent (reasoning, planning, reactive and pro-active characteristics) are applied for efficient and flexible transport-service management. The SAPS agent (Fig. 2*b*) utilises interactive and collaborative theories [11, 12].

Core SAPS agents are supervisor (or negotiating) agents (SA and Co-SA), the PIAs and the UIAs. The design and implementation of the intelligent agent-support commuter-transportation system reinforce strategic transportation goals, accommodates personalised commuter requirements and overall city and inter-city commuting demands.

The SAPS agents-support model facilitates effective collaboration between commuters and urban-transport services providers for mutual benefit, focusing on commuter requirements. On the one hand, commuters have 'on-time, real-time planning options' for their journey, and on the other hand helping in the management of urban-transport infrastructure. Fig. 2*a* demonstrates agent-support algorithms and flexible goal-oriented agent plans, which *enable the multi-provider collaboration system* to support users with diverse urban-transport requirements, achieve their commuting goals.

The IA (UIA) captures the commuter requirements, converting and identifying them into task(s) that are communicated to the



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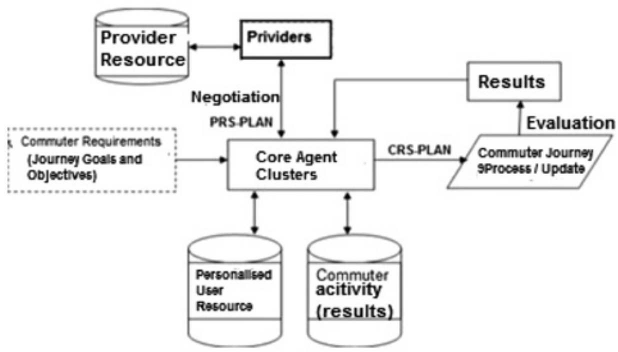

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Fig. 2 *SAPS agents and block diagram*
a Supervisor cluster agents – 'negotiate user requirements (captured by UIAs), with the PIA
b SAPS block diagram

Table 1 Commuter and provider requirements templates

User-requirement-template (UREQT)----------------	Provider-capability-template (PRVT)----------------
1) user name (s) ----------	1) provider ID (PID)----------------
2) tel no (UOIa):----------------	2) provider-name ----------------
3) email (UO1a) ------------------	3) provider associate-agency ID:----------------
4) location (pick-up address) (U02):----------------	4) provider associate-agency name: ----------------
5) destination dddress (U03):----------------	5) resource ID (CID):----------------
6) number of users (UO4) ----------------	6) resource name :----------------
7) resource - vehicle preference (U05) (if known)----------------	7) resource used by: ----------------
8) agent profiling: (auto-generate: best service routes for user) ----------------	8) available resource type (normal, green)----------------
9) proposed cost–U05 (Yes / No)----------------	9) available resource quantity----------------
10) negotiated cost (if applicable-UO6) ----------------	availability (minutes, hours, days): ----------------
11) time-scale requirements----------------	11) brandi / location ID----------------
	12) current-trip cost: ----------------
	13) negotiated-tripcost----------------
	14) company-agent-broker-commission----------------

SA/Co-SA. In response, the SA engages a 'mutually beneficial negotiation process' on behalf of the commuter and the requirements of urban city transport management services identify 'available green transportation resource options'.

The process apply SAPS 'Green Classification Algorithm, Section 3.4, Table 2' for best-routing, 'available low carbon emission resources' in real time and 'weighted commuting cost'; providing options for negotiation, from multiple-urban-transport providers, based on commuter personalised requirements. An updatable CRS-PLAN is generated based on responses and further interaction of the commuter.

SAPS commuter-support agent cluster (UIA, SA and co-SA), apply dialogue-templates (Table 1), to establish the unique commuting service plan, for each commuter request; generating personalised resources for a commuting trip.

Urban city commuting providers (and their provider agents – Fig. 3), with diversified capabilities (i.e. resources) demonstrated with the SAPS prototype infrastructure (see Section 3.4) offer competitive services, accessible to commuters in the entire region (urban city).

The commuting parameters: duration (Commute-D), target cost (Target-C), available transportation types and available providers are updatable in an evaluation process, for all commuting journeys.

The adaptive feedback process of the system helps delivery of personalised urban transportation services and enables commuters utilise cost-effective low CO_2 footprint options and effective

Table 2 SAPS green-transport-resource classification

S/N	RVI					TRVO
	Vehicle-type	Engine-size, l	People-capacity	Millage, miles	First-registration (age)	Green value
1	full-battery powered	<1.5	4–7 seater	<10,000	(<15 years)	green-type 1
			,,	>10,000	(N/A)	green-type 2
			,,	(N/A)	(>=25 years)	green type 3
			>7 seater	<10,000	(<15 years)	green-type 4
				>10,000	(N/A)	green-type 5
				(N/A)	(>=25 years)	green-type 6
			>=10 seater	<10,000	(<15 years)	green-type 7
				>1000	(N/A)	green-type 8
				>(N/A)	(>=25 years)	green-type 9
2	full-battery powered	>=1.5	4–7 seater	,,	,,	green types 10–12
			>7 seater	,,	,,	green types 13–15
			>=10 seater	,,	,,	green types 16–18
3	full-battery powered	>=2.0	4–7 seater	,,	,,	green types 19–21
			>7 seater	,,	,,	green types 22–24
			>=10 seater	,,	,,	green type 25–27
4	semi-battery and petrol powered	<1.5	(N/A)	(N/A)	|(NA)	semi-green 1
5	,,	>=1.5	(N/A)	(N/A)	(N/A)	semi-green 2
6	,,	>=2.0	(N/A)	(N/A)	(N/A)	semi-green 3
7	semi-battery and diesel powered	<1.5	(N/A)			semi-green 4
8	,,	>=1.5	(N/A)	(N/A)	(N/A)	semi-green 5
9	,,	>=2.0	(N/A)	(N/A)	(N/A)	semi-green 6
10	full petrol	<1.5	(N/A)	(N/A)	(N/A)	not-green 1
11	,,					
	>=1.5	(N/A)	(N/A)	(N/A)	not-green 2	
12	,,	>=2.0	(N/A)	(N/A)	(N/A)	not-green 3
13	full diesel	<1.5	(N/A)	(N/A)	(N/A)	not-green 4
14	,,	>=1.5	(N/A)	(N/A)	(N/A)	not-green 5
15	,,	>=2.0	(N/A)	(N/A)	(N/A)	not-green 6

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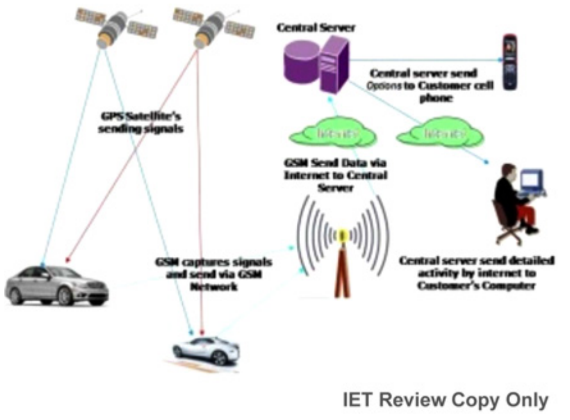

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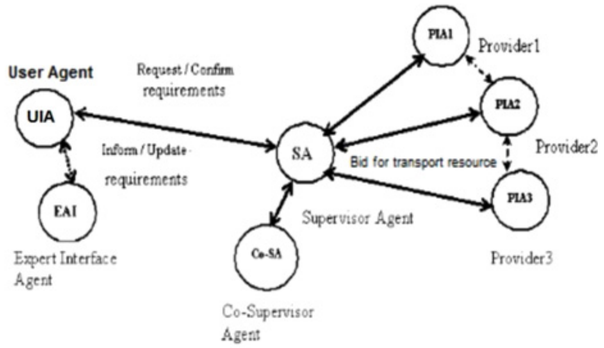

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Fig. 3 *Overview of SAPS operations and key agent interactions*
a Overview of SAPS operations environment
b Key agent interactions of SAPS system (UIAs, SA and PIAs

management of urban-transport infrastructure, for greener cities. Hence, the key component of SAPS agent infrastructure consists of: *(a) commuter requirements composition*; *(b) negotiation of commuter requirements*, *(c) composition of commuter-routing plan*, *(d) provider routing plan* and *(e) personalised-transport resource(s)*.

3.1 System input-commuter requirements

The input parameters for SAPS approach are constituted from: commuter location, pick-up time, commuter destination and other personalised requirements for the journey, as shown in Table 1, which are captured by the UIA with the aid of a user-requirements template.

3.2 Negotiation with providers: systems out

SAPS output 'Commuter Route (s)' and 'Transportation Options' for the commuters, as results of processing commuter request (or orders).

The PIA negotiates with the SA and/or Co-SA to process user-specific requirements of a commuter.

The UIA communicates tasks and sub-task to the SA, responsible for the negotiation with different urban-transport providers. SA initiates bidding and negotiation (Figs. 3*a* and *b*) with the urban-transport providers (PIA). Participants in the processing phase are depicted in the scenario below (Fig. 3). SAPS algorithm (Section 3.4) processes negotiations with multiple providers applying commuter requirements as key inputs: 'journey destination', 'pick-up location or locations'; to provide 'optional resources and routing flexibility to destination, 'cost/duration of the journey'.

At the 'transport systems level', it generates urban-transport indicators and profiles, consisting of personalised-transport resource(s) or [personalised resource (P-Resource)], CRS-PLAN and PRS-PLAN, for each negotiation/commuting activity.

The CRS-PLAN maintains a record of commuter requirements and commuting goals; as well as serves as index to P-Resources, while corresponding provider-plans specify terms and conditions, confirmed by commuter with the provider(s) for specific commuting journeys, in the negotiation process.

3.3 Commuting–journey evaluation

SA and Co-SA evaluate and renegotiate resources with providers (on behalf of the commuter), as necessary, for the commuting journey. Dynamic commuting service (DCS)-PLAN and PRS-PLAN maintain information about commuter requirements.

3.4 SAPS system processes

The process steps that map SAPS features are summarised as follows:

(i) Commuter requirements composition/commuter request.
(ii) Commuter requirements negotiation with providers.
(iii) Composing CRS-PLAN.
(iv) Composing provider routing service plan (PRS-PLAN).
(v) Evaluation and update CRS-PLAN and PRS-PLAN.
(vi) Review/update (1)–(5) as appropriate.

The evaluation of commuter destination, CORT-options and transport-resources options involves re-formulating the commuter request; hence, the process iterates, from steps (1) to (5). The algorithm exits when commuter–destination target(s) in DRS-PLAN are accomplished. Expert interface support agents assist in provider-resource assessment.

Two major categories of agent activities of the SAPS system are: agent-to-agent interaction for commuter-support and commuter-provider interaction for 'resource bidding' with providers. This is further illustrated in the agent infrastructure and communication components as follows.

Agent-infrastructure for flexible urban transportation: Agent-to-agent interactions of the SAPS system managing tasks on behalf of the commuter. The UIAs, expert IAs (EAIs), PIAs and SA, work in collaborate to analyse commuting task requested, assign and manage tasks generated from user requirements. The roles of the later agents include monitoring commuting–journey updates, support to users on specified destinations, providing commuters with provider options, to achieve cost-effective and environmentally 'green' journeys.

The agents' collaboration manages routing-activities. Agents' activities that support the SAPS process steps are:

a) *Reactive behaviour:* Where SAPS commuting-support agents, respond to events such as route-diversions, changes of weather forecast, accidents (if any), change of target destination and other personalised commuting requirements.
b) *Pro-active behaviour:* Where designated agent plans, based on triggers or events, provide suitable commuting–journey support, to meet specified commuter destination(s). Pro-active behaviours are triggered by perceiving problems with commuter-journey, from data collated in the course of the commuters' journey.

Agent-information communication components: The system employs a tripartite collaboration of: commuter-to-agent, agent-to-agents and provider-to-provider to generate optimal and personalised commuting services. Fig. 4 illustrated the structure of core information component, processed by designated agents. The *commuter request* component constitutes a summary of commuting objectives: destination, number-of-persons, start-time and estimated journey duration. *P-Resources, unique to the commuter,*

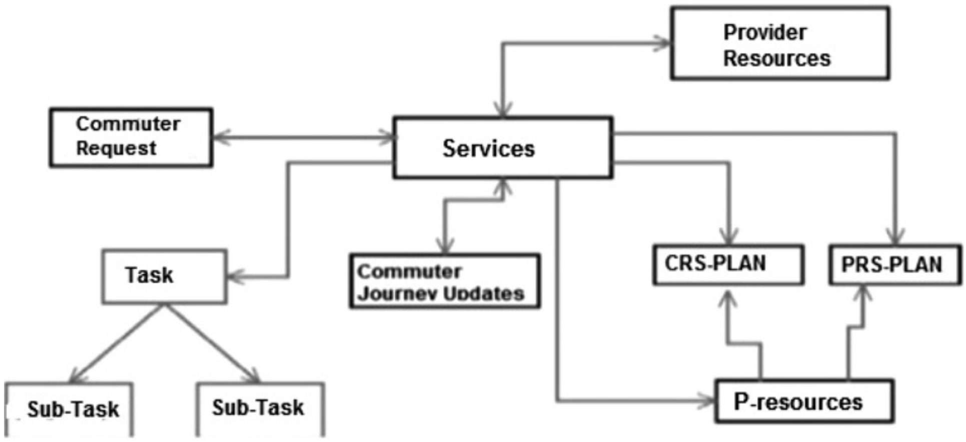

Fig. 4 *SAPS information structure*

and/or are generated from the commuter requirements, whereas the *provider commuting-plan (PRS-PLAN)* component keeps record of the resources and the terms and conditions of the commuters' journey.

The CRS-PLAN *component records the* engaged resources and corresponding commuter requirements, breakdown commuting tasks and target destination, while '*Results*' component tracks on-going accomplishments or missed commuting tasks of the commuter-journey. The box labelled *Services* (Fig. 8) shows the information structure that the agents utilise while supporting the commuter. It also represents information-flow of various agents that provide services to commuter. The arrows represent direction of information-flow between the various components of the system, associated with the designated agents.

The SAPS agent's services process: SAPS agent services capture and validate commuter requirements generating task and sub-task to accomplish target objective (*the destination*) of the commuter. The requests for commuting resources, generated from the requirements, are submitted to providers/provider agents, who in turn generate and submit bids, for commuter consideration; hence, empowering commuters with transportation (or commuting) resources options, from multiple providers.

The process offers commuting modes/commuting resources options (personalises resources or P-Resources) to commuters, not only based on personalised requirements, but also with emphasis on 'minimising carbon footprints'. This is achieved with a 'carbon footprint minimisation algorithm (CARFM)', applying Table 2 (SAPS Green Transport Classification), which evaluates 'eligible low-cost and environmentally friendly available routes' on behalf of the commuter(s). The agent system captures further commuter activities (update request, road incidents, duration and distance covered, alternative routes and resources where applicable) for the commuter-journey; hence, updating commuting plan and provider service plan; optimising and re-routing for cost effectively and eco-friendly urban commuting.

SAPS 'intelligent agent process' contribution in providing flexible 'routing options' to reduce carbon foot prints, with long-term personal and environmental cost servings; compared with 'immediate short-term commuter monetary savings'. A fully battery powered available transportation vehicle, as an example, may cost 2% more for a 10 min journey, but saves environmental pollution (CO2 emissions) with a diesel power vehicle that cost, for the same journey; with huge long-term environment CO_2 consequences. This can be also compared with the option of a public transport system (tram/trains/semi-petrol/semi-diesel vehicles) that has similar cost, but takes much longer time, with moderate pollution levels, as would be the case, in comparison with diesel vehicle transport. Thus, the SAPS process helps collate commuter usage on

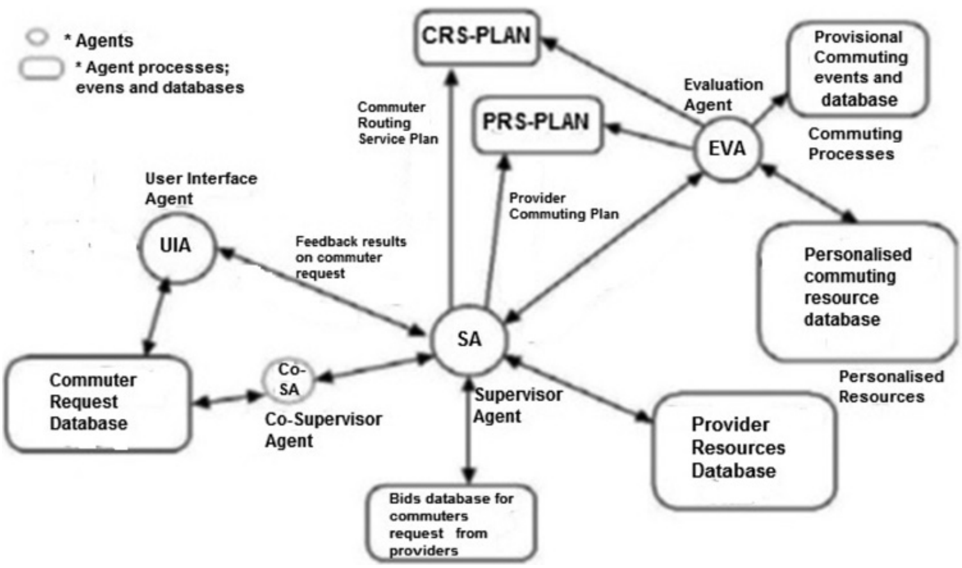

Fig. 5 *Instance of SAPS showing agent access to user requirements, commuting process and commuting resources*

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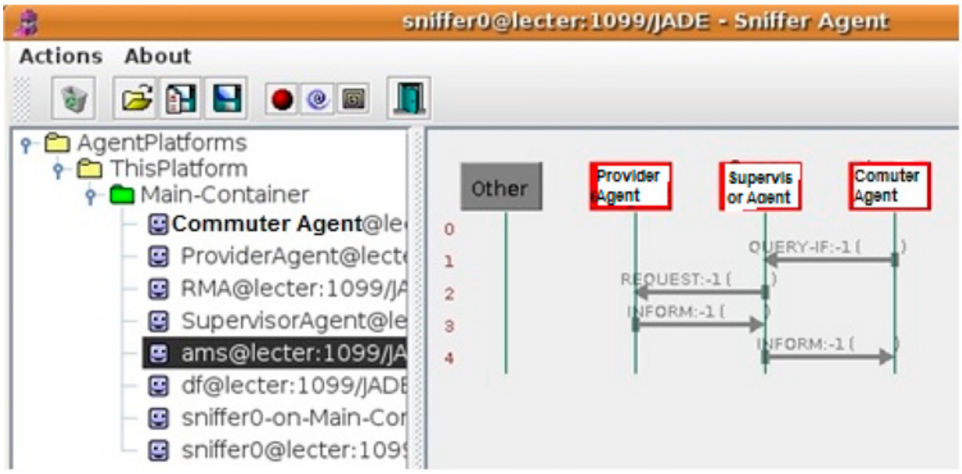


Fig. 6 *Message sequence between provider, supervisor and commuter/UIA*

the range of urban-transportation resources available, and providing intelligence in updating and optimising the urban-transport infrastructure to achieve 'greener cities status'.

Processing green transport resource for commuters: This process implements a CARFM), based on commuter destination, number of commuters and pick-up location amongst key commuting indicators (Section 3.1, Table 1). The variables of commuter resources examined are weighted by the CARFM, *generate a range of transport-resource variable outputs or* TRVO – [green-type1, …, *n*; semi-green 1, …, *n*; not-green 1, …, *n*' (see Table 2)]. The process supplements the commuter request (or orders), with resource variable input (RVI): vehicle-type; engine-size; people-capacity: millage, car-reg. and age, to achieve the 'best eco-friendly TRVO' applicable to the request (or commuter requirement).

The CARFM process achieves mainly two goals: determines and records 'rate-of-usage' of the overall urban-transport status (by generating traffic-flow and infrastructure-usage matrix, for management review and update); as well as providing 'green available solution' to commuters; hence, addressing issue of urban-transport infrastructure, CO_2 emissions and carbon footprints.

Fig. 5 illustrates 'a snap-shot' composition process of commuter requirements and bidding for commuting resources from providers; the SA and Co-SA co-ordinates the key activities of task distribution, commuting requirement analysis and feedback process of the SAPS system in the negotiation process with urban-transport-provider agents, while the 'agent cluster' of UIA, evaluation agent (EVA) and SA agents maximises available transportation resources for the commuter.

The dedicated EVA monitors the transportation process, which generates feedback, proposes options and recommended actions for the commuter. While the SA interacts regularly with the commuter IA (UIA) to capture further commuting requirements; in case of 'zero updates', it proceeds with 'a start of journey default CRS-PLAN'. Typically commuter destination, (DSID), factored pick-up-points and CORT ID are constituted in a 'default CRS-PLAN' for a commuter-journey, but updatable for the duration of the trip.

4 Analysis of SAPS contributions

On the basis of current commuting issues of 'on-time access', 'eco-friendly' and 'cost-effective urban commuting', this paper posits the following contribution:

C1) Contract-based flexible and personalised urban-transport services: This is SAPS overall process underpinned by contracting urban-transport resources from multiple providers. The six-step iteration process (Section 3) ensures delivery of personalised urban-commuting, applying intelligent agent collaboration and negotiation capabilities; it not only provided 'automated green commuting options for commuters', but also support for 'city transport infrastructure management strategy', for green-last-mile commuter resources.

C2) Devising and dynamically aligning CRS-PLAN and provider routing service plan: On the basis of commuter requirements and personalised urban-transport resources, intelligent agents manage commuting journeys with CRS-PLAN and PRS-PLAN that are strategic components of the adaptive agent infrastructure.

C3) Two-way evaluation of commuting activity: The approach applies pro-active agent behaviours in analysing and evaluating both target commuter requirements and urban-transport-provider capabilities for optimum routing.

In summary, SAPS agents adopt commuter's goals (requirements) and translate them into sub-goals (sub-tasks); negotiates commuting resources from multiple providers; with expert knowledge-based resources, to generate feedback of mutual benefit for both commuters and providers.

5 SAPS implementation

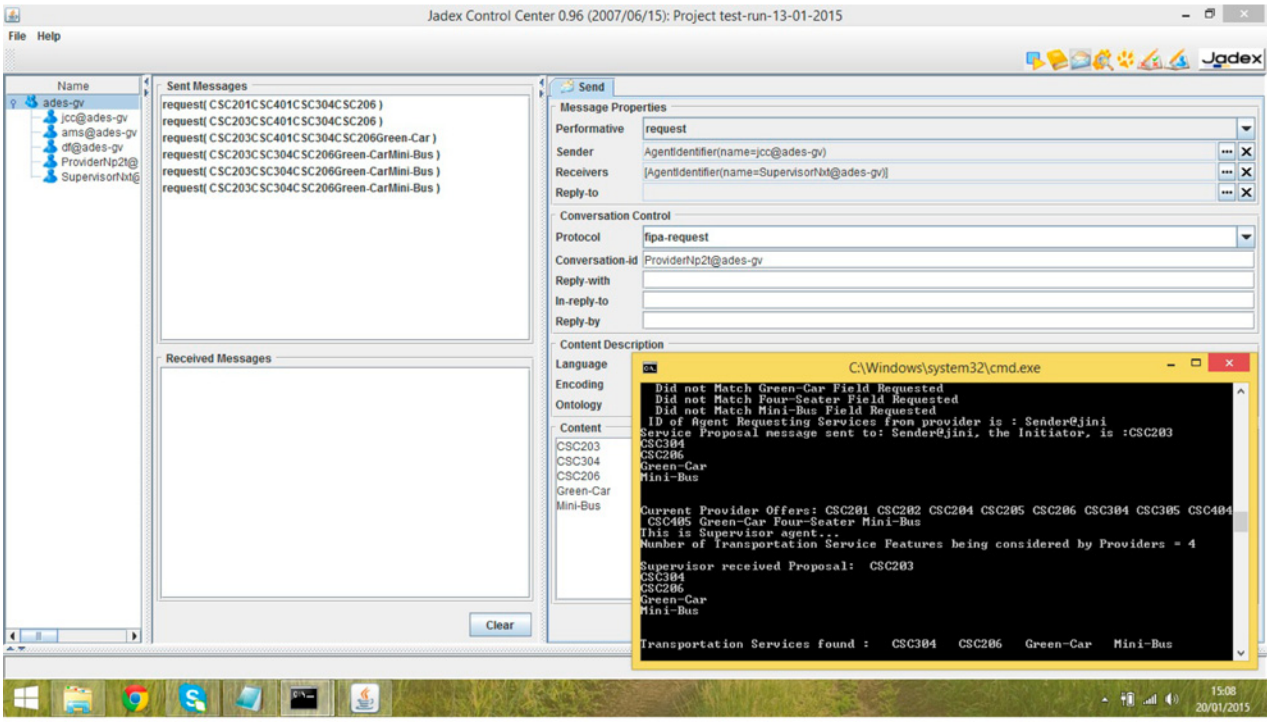
Figs. 6 and 7 demonstrate a proof-of-concept prototype implementation of SAPS, in Jadex agent development platform. Agent negotiation protocols, designed based on Foundation for Intelligent Physics (FIPA) specifications [13], facilitated negotiation of suitable commuting destinations for urban-transport users. The implementation of agents in the prototype system supports the contributions as shown in Tables 3 and 4.

The evaluation and feedback mechanism for monitoring commuter-routing process implements a range of automated agent plans, deciding for a given situation(s), the 'best plan of action', based on set environmental friendly targets, and commuter requirements. Discrepancies between 'target tasks' (user requirements on commencing the journey) and the 'current task' (the actual commuting situation) are flagged to both commuter and urban-transport provider.

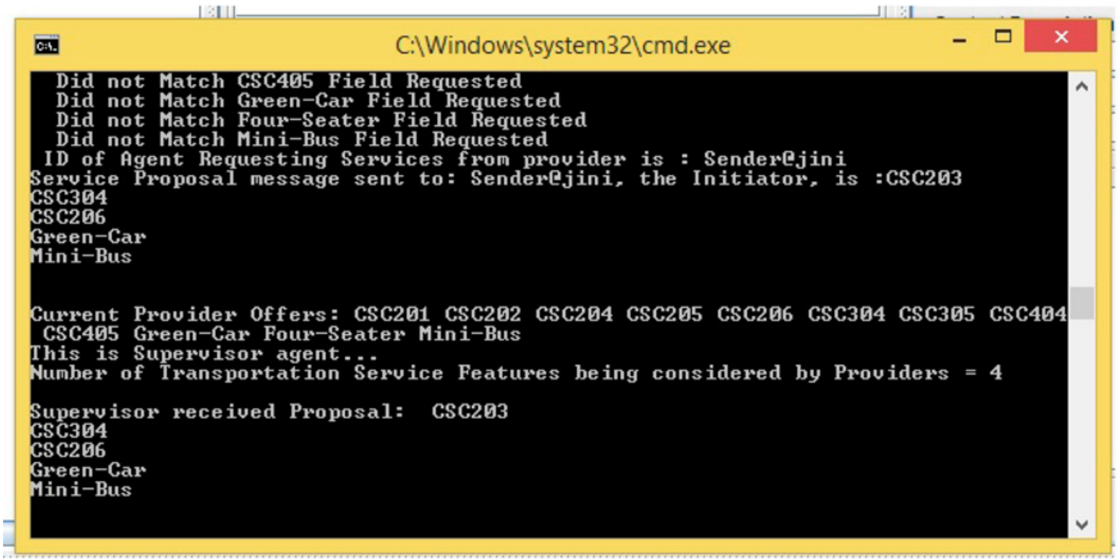
The commuter (represented by commuter agent) is prompted for various commuting options that include update of additional or supplementary 'routes' in CRS-PLAN, and/or review of commuting requirements; hence, reconstituting CRS-PLAN and PRS-PLAN as and when necessary.

5.1 SAPS prototype results

SAPS Sniffer agent (Fig. 6) monitor communication between the commuter IA (which generates queries of commuter requirements)



a



b

Fig. 7 *Results of urban-transport support agents activities, demonstrating typical transport services offers to a commuter*
a Capturing commuter requirements and feedback of commuting options from providers
b Provider offers (or bids) feedback to commuters, based on the orders/request
c Graph of weighted cost of commuter options for a 30 miles journey

and the SA. The queries trigger an SA to request for commuting resources from various urban-transport providers, who subsequently bid (or make suitable) offers, applying CARFM (Table 2), based on the request; and hence the commuter makes informed choice about their target destinations.

The re-active and pro-active agent behaviours, assisted by 'commuting evaluation algorithm', pro-actively take 'readings', when 'actual situation on the road' differ from initial goals and objectives of the commuter. The implemented agent protocols (inspired by FIPA Contract-Net specifications), with request parameters ('pick-up points', 'commuter-journey duration' and 'destination-route summary description'), carry out bidding of personalised urban commuting resources, from providers.

The results demonstrated flexibility and efficiency of applying the believe desire and intention) agents and modelling of flexible and personalised urban-transport requirements.

5.2 *Analysis of SAPS intelligent agent system*

The screenshot (Figs. 7*a* and *b*) captures activities of the SA (*SupervisorNXt*); provider agents, *ProviderNP2t* (PIA); and the Jadex Control Centre agent (JCC), which represents the UIA agent. The User (or commuter) request is processed and represented as 'coded inputs: CS203…CSC206) that are communicated to transport-service provider agents and the results (commuting resources offers or proposals) presented to commuters (JCC

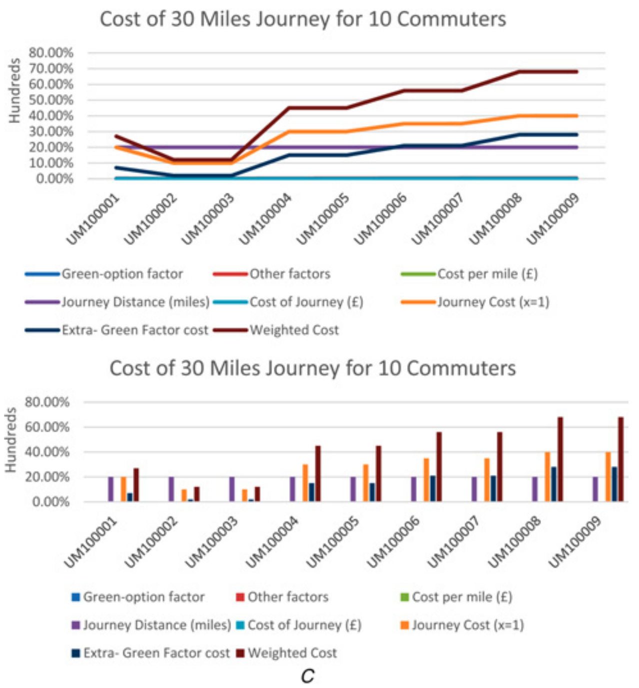


Fig. 7 *Continued*

agent) for confirmation. The commuting offers (or options) made available to the commuter, thus depends on the time of the day, available resources and affordable capacity of the commuter. The commuter requirements supplemented with Green urban commuting requirement, processed by SA in collaboration with PIA apply the negotiation criteria Table 3.

Figs. 7*a* and *b* detail message exchanges between the user support agents (UIA) and SA; and the provider agents (PIA). The results of negotiation (or available service options), shown, include four available offers (Mini-Bus, Green-Car, 206 and 304 transport-service resources) proposed by the providers for the commuters' review in the process; and the requested services are rendered when an option is confirmed.

Analysis of captured and existing data, applying SAPS template: Sample data profile from existing systems (as shown in Table 5 and plotted in Fig. 7*c*), illustrate a cross-section of data from: (a) BT information hub for IoT transport sector [14]; (b) open data, on busy commuting routes [15]; and (c) weather data for planned road works.

The case study data profile structure (Table 6) for the SAPS agent system examined a 30 miles sample use-case with, provider ID, pick-up points, destination, green and surcharge factors that affect the carbon emission footprint and duration of the commuter-journey. The surcharge factor accounts for 'Group Travelling' and hence the volume of CO_2 emissions for the journey. The weighted cost of the journey (WCJ) is computed from the variable represented by the equation:

WCJ = (K + th)x/100 + jdx, where: x = cost per mile (in this case £1.00 per/mile); k = green factor and cost of green factor = kx/100; while cost of other factors (th) = thx/100; jd is journey distance (in miles) and the CJ is the product of journey distance (JD) and cost per mile for the journey, CJ = jdx.

WCJ is weighted cost of journey, computed from the cost of the distance covered (a product of the number of miles and the cost per mile), added to the percentage cost of the green factor and other factors as shown in this table.

The case of $x = 1$, (journey cost of £1.00 per mile) was implemented. The computed JD was taken from the commuter location and requested destination of the commuter, while the cost per mile was obtained from case study of the average transport cost of UK government and private sector regulations. The green factor (*k*) and other factors (*th*) were derived from environmental data on cost of pollution of CO_2 emission, per mile, for a range of vehicles.

Supplementary key data involved in the commuters' journey included: time of day, traffic data (peak time, off-peak/ non-office-hour times; available transportation resources for public, private or last-mile journeys; and other factors such as weather conditions. Each commuter request represented the key variables of: commuter name/reference ID; current location (address); destination location (address) and transportation Type (four seat vehicle carrier, seven seat vehicle carrier etc.).

The results demonstrate that cost of CO_2 emissions are reduced by optimising the commuter route (JD), from a 'pick-up-point'

Table 3 Agents activities and contributions

S/N	SAPS	Agent						
	Contributions	SA	Co-SA	UIA	PIA	EAI	EVA	PA
1	C1	√	√	√	√	√		√
2	C2	√				√	√	
3	C3	√		√		√	√	

Table 4 Negotiation with multiple providers: criteria and decision tables

Negotiation Issues	Commuter Request	Provider Offer	Negotiation Criteria Action (Provider)		Action (Commute)
green-option (CO_2 Level)	L-Green	P-Green	if L-Green is same as P-Green, Set% Counter, Accept>50%, else consider proposal	proposal	counter-proposal
time of the day (peak, off-peak, non-office-hours)	L-Duration	P-Duration	if L-Duration is same as P-Duration, Set % Counter, Accept>50%,, else consider proposal	proposal	counter-proposal
t-resource type	L-Summary	P-Summary	if L-Summary is same as P-Title, Set % Counter, Accept>50%,, else consider proposal	proposal	counter-proposal
journey cost	L-Price	P-Price	if L-Price is 80% and above-accept; 50% and above, Neg. proposal, less than 50% -reject	accept on 80% and reject<80%	offer 80% and above

Table 5 Implementing variable transportation cost per mile ($x = 1$)

S/N	Commuter ID	T-ResourceID	Green-option factor	Other factors (%)	Cost per mile (£)	Journey Distance (miles)	Cost of Journey (£)	Weighted Cost
1	UM100001	CSC201	2	2	X	30	30x	65
2	UM100002	CSC204	2	4	X	30	30x	70
3	UM100003	Estate–4 seater	3	–	X	30	30x	90
4	UM100004	Saloon–4 seater	3	–	X	30	30x	90
5	UM100005	7 Seater	4	3	X	30	30x	127
6	UM100006	9 Seater	4	3	X	30	30x	127
7	UM100007	5 seater	4	3	X	30	30x	127
8	UM100008	CSC504	5	5	X	30	30x	165
9	UM100009	4 seater	5	5	X	30	30x	165
10	UM1000010	CSC304	5	5	X	30	30x	165

and commuter destination; applying SAPS smart-agents algorithms and the 'green-carbon emission policy', Table 2, to obtain cost-effective, personalised and flexible routing.

6 Evaluation of the SAPS system

The innovative features of SAPS implement dynamic commuter-routing service plans and urban provider routing services for personalised and flexible commuting. It improves management of distributed and re-usable urban-transport resources, compared with existing static legacy infrastructure. The high-level evaluation indicators: 'Commuter requirements analysis and clarification', 'Dynamic Commuting-Plan' and 'Two-way evaluation of commuting-processes', tabulated in Table 6, highlight the advantage of SAPS, over existing systems.

Commuter requirements analysis and commuting goals: Unlike existing approaches, SAPS commuting system analyses and updates personalise commuting requirements in real-time to achieve 'clear commuting goals' to help establish 'green commuting infrastructure'. SAPS translates defined-goals (personalised journey requirement) to eco-friendly multi-provider offers. Existing approaches such as UBER, STRIDE and MODUM have predefined user-requirements model, with fixed commuting goals that are not modifiable by the commuter.

SAPS uniquely addresses the issue of clarifying commuting goals and commuting objectives. In this respect, SAPS extends existing systems such as MODUM with dynamic commuting objectives, and options for flexible urban transportation.

Commuter-routing service plans: The flexible routing components of SAPS (CRS-PLAN and PRS-PLAN) differentiate SAPS from UBER, STRIDE, MODUM and similar systems that utilise fixed commuter preferences, in a fixed transport-commuting model. The flexible agent architecture of SAPS and functionality of CR36S-PLAN provides supports update of commuter requirements, in the commuting process.

Modelling commuters' needs (effective use of resources): In the previous work, UBER and MODUM [2, 16] are based on modelling commuters with limited (single provider) resources. In contrast, SAPS focuses on applying deliberative agent capabilities [29, 30] and facilitates dynamic modelling of commuters' needs in a multi-provider environment. Similarly, SAPS contrast with UBER approach [2], which deals with a fixed commuter-requirement model, without consideration for the environment and CO_2 footprints.

Effective use /re-use of green commuting resources: Negotiation of transport resources with multiple providers as well as the 'commuter requirements gathering and processing phase' is unique to SAPS. While pre-SAPS systems may implement mechanisms with some measure of 're-use of transport resources', the application of agent-based negotiations of SAPS not only brings more flexibility in the urban – commuter-routing process, but also engages multiple providers to provide 'best environmental friendly solutions' to commuter requirements.

Table 6 Summary comparison of adaptive e-learning approaches and features

S/N	e-Learning issues	UBER	STRIDE	MODUM	SAPS
1	commuter requirements analysis and clarification	(√)			√
2	dynamic commuting-plan				√
3	two-way evaluation of commuting-processes		√		√
4	modelling commuter requirements for 'smart-greener cities'			√	√
5	effective use/re-use of green commuting resources				√

(√) Partial implementation.

7 Conclusion/summary

SAPS improves existing urban-transport service, utilising innovative agent-algorithms and capabilities (agent learning, planning and negotiation techniques), for effective management and process commuter-defined and updatable-functional-specification. This contributes to responsive and efficient public transport services, focusing on the commuter requirements; contributing to 'city transport infrastructures 'Green Last-Mile Resources'; and automating green commuting options for commuters. The 'energy aware' and 'eco-friendly' systems harness pro-active capabilities of intelligent software agents [23, 25], contributing to flexible and personalised commuter-transport services.

SAPS negotiation and multi-provider-contracting functions, empower both commuters and urban-transport operators, with mutual benefit between urban-transport providers, on the one hand; and the commuters on the other, who are the urban-transport users. The innovative evaluation and feedback mechanism enables commuters adopt changes on current commuting situation.

8 Future work

Future work on SAPS would examine national and subsequent international applications with IoT [22, 24]; and the wider impact on environment and population growth.

Research and development of key analytical agents with relevant data sets [17] samples accumulated with SAPS and related systems, would also be critical in extending the system, given key regional cloud infrastructure challenges.

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