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No. 88
Intelligent Transport Systems
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Editorial Statement

The Transport and Communications Bulletin for Asia and the Pacific is a peer-reviewed annual journal published by the Transport Division (TD) of the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP). The main objectives of the Bulletin are to provide a medium for the sharing of knowledge, experience, ideas, policy options and information on the development of transport infrastructure and services in the Asia-Pacific region; to stimulate policy-oriented research; and to increase awareness of transport policy issues and responses. It is hoped that the Bulletin will help to widen and deepen debate on issues of interest and concern in the transport sector.

Solving transport issues requires simultaneous implementation of multiple countermeasures. In recent years, there have been great advances in telecommunications, automotive systems, electronics and computer technologies, which have enabled new innovations in transport systems, resulting in Intelligent Transport Systems (ITS). ITS can be an important tool for providing far-reaching solutions to pressing issues facing transport systems, ranging from accessibility, reliability, and efficiency to safety.

In 2015, the United Nations 2030 Agenda for Sustainable Development was adopted by the General Assembly. The 2030 Agenda puts forward a total of 17 Sustainable Development Goals (SDGs) and 169 targets to stimulate actions in areas of critical importance for humanity and the planet. Transport is recognized as an important means of achieving various SDG goals and targets. In Asia and the Pacific, transport either directly or indirectly contributes to SDG goals 1, 2, 3, 7, 9, 11, 13, 16 and 17.

In this background, ESCAP TD has initiated several projects relating to ITS considering the potentials of ITS in Asia and the Pacific, and the current issue of the Bulletin focuses on the theme of “Intelligent Transport Systems”. Each of the four papers considers different interesting aspects of the subject.

a. An advanced web-based support system for road safety decision-making by Fabio Galatioto, Mario Catalano, Nabeel Shaikh and Erik Nielsen
b. Role of Intelligent Transport Systems (ITS) applications in the uptake of mobility on demand services by Patrizia Franco, Ryan Johnston and Ecaterina McCormick
c. Approach to prioritizing Intelligent Transport Systems (ITS) services in developing countries – the Mongolia case by Jaehyun (Jason) So, Mijeong Kim, Taehyung Kim, and Suran Son
d. Cost effective evaluation study of intelligent public transport system based on social investigation by Xiaoliang Zhang, Dongmei Liu and Jing Wang

The four papers have been selected on the basis of the review process by the editorial board which consists of internal and external review panels at the professional level. These studies and analyses have directly or indirectly contributed towards understanding the means in which ITS can help to achieve one or more SDGs in a meaningful manner by informing us in both theoretical and practical ways how this can be possible. This Bulletin have attained further insight into the topic and received interesting conclusions and recommendations. It is expected that the current issue of the Bulletin “Intelligent Transport Systems” would generate further debate and provide a point of reference for discussion among policy makers and researchers.

The Bulletin welcomes analytical articles on topics that are currently at the forefront, of transport development in the region as well as policy analysis and best practices. Articles should be based on original research and should have analytical depth. Empirically based, articles should emphasize policy implications emerging from the analysis. Book reviews are also welcome. See the inside back cover for guidelines on contributing articles.
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AN ADVANCED WEB-BASED SUPPORT SYSTEM FOR ROAD SAFETY DECISION-MAKING

Fabio Galatioto*, Mario Catalano**, Nabeel Shaikh*** and Erik Nielsen****

ABSTRACT

This paper illustrates the results of the research conducted under the MAIA (Models and methods for collision prediction and Impact Assessment) project to develop a web-based platform for performing road safety simulation and assessing crash-related externalities.

After outlining the cutting-edge of accident prediction science as well as the state of the art of web-based road safety simulation, the paper describes an application in the United Kingdom, resulting in the development of the novel MAIA toolkit. This uses a set of three collision prediction models deriving from the comparison of a number of statistical parametric and machine learning methods (count data, ordered multinomial and artificial neural network models), along with an impact assessment tool. The MAIA prediction models estimate the frequency of road collisions and their casualty effects: number and severity of injuries; whilst the MAIA impact assessment tool has been designed and tested to estimate collision impacts (travel times, costs and emissions).

The prediction models adopt a statistical parametric framework, which has proved to perform better than non-parametric methods and have been validated on a national as well as subnational (cluster of UK districts) level.

In the Asia-Pacific region, hundreds of thousands of people die every year due to road accidents. In line with the United Nations “Decade of Action for Road Safety 2011-2020” Resolution, a web regional network has been created for the exchange of road safety best practices within the Asia-Pacific area. The idea behind this paper is to provide a scientific and robust set of tools, which potentially could be integrated through a web-based application to estimate the parameters of context-specific accident prediction models and support road safety decision-making at different scales.

Keywords: road safety decision-making, road accident prediction, web-platform, statistical parametric models, machine learning.

INTRODUCTION

Given the rise of motorized transport throughout the world in recent years, road accidents analysis and prevention are now a priority challenge for policy makers. In fact, in 2010 the United Nations (UN) General Assembly proclaimed the 2011-2020 period as “the Decade of Action for Road Safety” (Resolution 64/255), with the aim of stabilizing and then reducing the forecasted levels of road fatalities on a global scale (United Nations, 2010). To achieve this goal, the World Health Organization and the United Nations regional commissions, in cooperation with the United Nations Road Safety Collaboration and other stakeholders, have been asked to prepare a Plan of Action for the Decade as a guiding document to support the implementation of its ambitious objectives, fostering road safety management expertise, improving the safety levels of transport networks and vehicles, influencing the behaviour of road users accordingly and enhancing post-crash response to name few. In addition, Resolution 64/255 invited

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the World Health Organization and the United Nations regional commissions to coordinate regular monitoring, within the framework of the United Nations Road Safety Collaboration, of global progress towards meeting the targets identified in the plan of action through global status reports on road safety and other appropriate monitoring tools (World Health Organization, 2010).

Accident prediction modelling can provide a solid basis for road safety decision-making, in line with a culture of scientific evidence-based planning: accident prediction models can help public authorities to identify the actual sources of road hazard and estimate the potential effects of policies and management actions, in terms of crash frequency reduction and severity mitigation.

A recent study (Yannis et al., 2016) points out that most organizations involved in road accident prevention – in Europe, the Asia-Pacific region and the United States of America – do not use prediction models for road safety decision-making on a regular basis: in more detail, although about 60 per cent of the organizations interviewed (national road authorities, managing companies, academia/research institutes and highway consultants) usually derive their choices or proposals from a comparative analysis of alternative road safety measures, they rarely or never employ accident prediction models during the assessment process. This is probably due also to the shortage of easy-to-use applications and toolkits to support policy makers and practitioners in road safety promotion by the use of accurate predictive models. In fact, as the following section shows in detail, from the technological point of view, the state of the art mainly consists of simple web databases of effective safety measures (Yannis et al., 2016), which raises a serious gap hindering the global advancement of road safety levels.

This paper describes the early results of an ongoing research that, in an attempt to address the above gap, proposes a web-based platform (MAIA - Models and methods for collision prediction and Impact Assessment - toolkit) for road safety policy/measure simulation at both national and local scale. The core of this web application will consist of models to predict the main dimensions of road collision phenomena (crash frequency, number of casualties and severity) and to assess impacts of collisions in terms of non-casualty effects, such as congestion, travel delays and emissions. In its current form, the MAIA toolkit incorporates only models for accident prediction, which derive from a complex development, validation and selection process: more than 300 models from both the microeconometrics domain and the machine learning area have been evaluated.

For the specific case of the Asia-Pacific region, the current availability of a regional web-based network to facilitate the regular exchange of road safety best practices amongst government officials and practitioners (Asia Pacific Road Safety Network) makes this research particularly considerable for the region’s stakeholders. In fact, this network could be the first step of a process to harmonize and share road safety data within the area, thus creating the basis for the development of a system of accident prediction models to be integrated into the regional web network as a MAIA-like application. Every collision aspect (number of casualties, severity, etc.) could be modelled with a clustering approach, which means building several cluster-specific simulation tools for the same aspect, each cluster consisting of data from similar countries/areas. This might yield the advantage of increasing significantly the information employed to model every specific crash dimension, in terms of sample size and wealth of predictors.

The paper, in section 2, explores the scientific literature about road accident modelling, with regard to crash frequency as well as casualty and traffic congestion effects; furthermore, section 2 outlines the main web-based decision support systems for road safety decision-making. Section 3 illustrates the novel MAIA toolkit and is followed by the description of the underlying accident modelling process in section 4 and the travel time impact estimation tool in section 5. Finally, conclusions are drawn and the future steps of the research are pointed out in section 6.

I. LITERATURE REVIEW

This section outlines the scientific literature on road accident and related external costs modelling and ends with the description of the most advanced web toolkits to support road safety policy-making and management. Exploring the relevant state of the art has revealed that, so far, safety scientists have mainly employed, as road accident predictors, transport variables such as traffic flows and speed, along with road geometry parameters. However, a more comprehensive approach is
emerging and may spread in the near future for the increasing availability of road operation data\(^1\), special conditions at the crash location (like, for instance, roadworks), carriageway hazards (like, for example, the presence of vehicle load on road), user behaviour (such as driving under the alcohol influence), weather conditions, land use in the area around the accident scene, etc.

The accident prediction models resulting from the research illustrated in this paper, instead, extends the set of explanatory variables far beyond the traditional one, so as to include many of the above-mentioned regressor types.

Moreover, unlike the MAIA toolkit, in general, the existing web-based road safety decision support systems do not use complex predictive models and are at most complementary to external accident models developed as single regressive equations for standard site configurations. In such cases, the web app suggests crash modification factors to adjust the crash frequency estimated for baseline conditions with external models, so as to take into account the real problem’s peculiarities (Yannis et al., 2016). This is the reason why the MAIA platform, conceived as a comprehensive simulation toolkit for road safety policy and management support, represents an advancement of the current state of the art.

A. Accident prediction models

In general, road accident prediction models are used to investigate the association between the likelihood of a certain level of crash frequency or severity and a set of potential explanatory variables, so as to elicit guidelines for public authorities to prevent collisions and alleviate their effects. So far, researchers in the field have explored a number of traditional and novel statistical methods to analyze and forecast road accidents, with particular regard to microeconometrics and machine learning models. However, they have mainly focused on transport predictors, such as traffic flows and speed, along with road design variables.

As to the application of econometric models, often the variable of interest it is of count nature (e.g. number of collisions, number of casualties, etc.), which requires the use of specific models of count data (nonlinear methods). The output is usually a positive probability function (e.g. probability of observing one, two, … casualties in a single crash). This means that the number of events to forecast (e.g. likely number of casualties per crash) is estimated as the average of a random variable.

To cite just one important example from the relevant literature, consider the RIPCORD-iSEREST research project, whose aim was promoting best practices in road accident forecasting according to the state of the art (Reurings et al., 2005). Based on a thorough investigation into the accident modelling science, generalized linear models using Poisson or negative binomial probability distributions were proposed as effective prediction tools. Also, the specific dimension of road crash severity has been investigated diffusely with statistical parametric approaches. In this case, the variable of interest can take one of several mutually exclusive outcomes (e.g. slight injury or severe injury or fatality) and, therefore, an appropriate and widely used prediction method is logistic regression (Cameron and Trivedi, 2005; Menard, 1995). An interesting example is the study by Bedard et al. (2002), who employed multivariate logistic regression to analyze crash severity and discovered that female drivers drinking, not using seatbelts and travelling at higher speeds increase the likelihood of fatal accidents.

Over the last years, various safety scientists have analyzed road collision phenomena by nonparametric methods, with particular regard to the application of machine learning to accident severity classification. In general, machine learning is employed to extract patterns from big datasets and build predictive models, without the need of assuming a specific mathematical form for the relationship between the variable of interest and its predictors.

The classification and regression decision tree (CART) is one of the most accredited machine learning methods in accidentology. An interesting example can be found in the study by Kashani and

\(^1\) As stated in Yannis et al., 2016, “road operation data are a little less common than road design data” and, when collected, in general, “are also not publicly available.”
Mohaymany (2011), who applied the CART approach to investigate rural accidents in Iran and found out that forbidden overtakes and not using seat belts are the most influential factors of collision severity.

Another notable nonparametric approach in accident severity research is the artificial neural network (ANN), as demonstrated in the work by Sohn and Shin (2001), which compares the ANN paradigm to the CART and logistic regression methods for road crash severity modelling in Korea. They showed that classification accuracy does not differ significantly across the three models and protective devices (seat belts and safety helmets) are the most determining predictors of accident severity.

B. Assessment of accident-related congestion costs

Estimating the cost of road collisions has been an active topic of discussion and has been studied quite thoroughly during the past few decades (Wijnen, 2017). One of the most thorough studies retrieved was developed by the European COST313 project (Alfaro et al., 1994). This project proposed guidelines regarding the cost components that should be included as well as the methods to estimate them. Although the externality of congestion due to road collisions is mentioned, unfortunately no relevant estimation methodology is presented.

Nonetheless, only a few studies trying to explicitly quantify the cost of congestion due to road collisions could be retrieved (Chen et al., 2016; BITRE, 2009; Dowling et al., 2004; and Hallenbeck et al., 2003). The most notable is the one conducted by the Bureau of Infrastructure, Transport and Regional Economics of Australia (BITRE 2009). In this study, a deterministic queuing model was used to estimate delays due to crashes. These queuing models assume that vehicles move uninterruptedly through a bottleneck up to a certain capacity. If the number of vehicles (flow) exceeds the capacity, then queues start to build-up. Making assumptions regarding the capacity of all links in the network, the average flow on these links depending on the time of the day, the value of time of the affected road users, the effect of crash severity in terms of delay and the response time of authorities, they managed to estimate the cost of congestion due to road collisions between $500 million and $1.76 billion. This wide range is explained by the significant number of assumptions made to come up to this estimate. The congestion cost percent value had been estimated to be around 10 per cent of the overall accident cost in an earlier study by the Bureau of Transport Economics in Australia (BITRE 2000). Few other similar but more simplified approaches were also retrieved (de Leur et al. 2010; Scottish Natural Heritage 2011).

The key point from all the relevant studies to the estimation of road crash-related delay costs is that, so far, they rely on simplistic assumptions regarding the network conditions (flows on links) and the actual delay caused by accidents, thus their results can be very informative but not entirely accurate.

C. State of the art of web-based road safety decision-making support

Exploring the pertinent literature led to find out four noteworthy web applications in the road safety field: the Federal Highway Administration CMF Clearinghouse databank (Gross, 2010; Gross, 2011; Yannis et al., 2016), the AustRoads Road Safety Engineering database (Jurewicz, 2010; Yannis et al., 2016), the iRAP Road Safety database (Yannis et al., 2016) and a recent crash risk prediction map from the Indiana State Police (Indiana State Police, 2016).

The first is directly related to the Highway Safety Manual (HSM), probably the most important guide for accident forecasting (AASHTO, 2010; AASHTO, 2014). The HSM provides predictive methods to estimate the crash frequency (by severity or collision type) of a network, facility or specific spot. The estimations are obtained with simple regression models developed for a set of base sites and named safety performance functions (SPFs). The SPFs depend typically upon only a few variables, mainly average daily traffic volumes and some roadway characteristics. The prediction performed by a safety performance function is to be adjusted if the actual features of the considered site differ from the base conditions of the model. To do this, crash modification factors (CMFs) are employed; these are particularly useful to estimate the effectiveness of safety measures. A number of CMFs are included in the HSM, but many others are provided by complementary guides and web-based platforms like the Federal Highway Administration CMF Clearinghouse databank, funded by the United States of America Department of Transportation. The CMFs provided by this platform are categorized on the basis of the site characteristics (area type, number of lanes and traffic volume) and the class of collision (angle crash, run-off-road collision, etc.).
The AustRoads Road Safety Engineering databank derive from extensive investigation into the effectiveness of several tens of road safety treatments in Australia and New Zealand. It offers transport planners the possibility of analysing accident phenomena by three criteria: crash type (head-on, rear-end, …), safety deficiency (road lighting inadequate, unclear priority, …) and road user (motorcyclists, pedestrians, …). Once a specific criterion is chosen, the related collision phenomena are illustrated, along with relevant engineering and non-engineering countermeasures. Furthermore, each treatment type is hyperlinked to a more detailed description including costs, benefits, implementations issues, technical references and a general measure of effectiveness in terms of crash frequency reduction percentage.

The iRAP Road Safety databank, through ViDA (iRAP online software) allows to access content including mapping and tables of results which have been built from road inspections and assembled from surveys of many kinds as a result of the collaboration between the International Road Assessment Programme (iRAP), the Global Transport Knowledge Partnership and the World Bank Global Road Safety Facility, is very similar to the AustRoads one, even though the former provides less precise measures of treatment performance. In fact, the effectiveness of each proposed treatment is evaluated on a four scale system: 0-10 per cent, 10-25 per cent, 25-40 per cent, 60 per cent or more. Furthermore, the treatment cost (in qualitative terms) and life (in years) are indicated.

In the end, in 2016, a new web application was launched by the Indiana State Police. This provides a Daily Crash Prediction Map showing with color-coded grids how the accident risk varies across the state road network during the current day. A machine learning algorithm is used for risk prediction on the basis of historical crash data, road conditions and characteristics, traffic volumes, information on residents and workers, time of year and day, etc. However, no simulation feature is available to assess the impact of alternative intervention scenarios on road collisions. Law enforcement officials can examine the map to pinpoint the hazard hot spots and, if necessary, move first responders to the highest risk areas. Travellers can use the map to check if their planned routes are in high risk zones, thus requiring re-routing or very cautious driving behaviours.

II. THE MAIA WEB APP FOR ROAD SAFETY POLICY AND MANAGEMENT SIMULATION

The MAIA web platform, which was developed in the first instance for the United Kingdom, gives easy and secured access to road collision model-based simulation, thus facilitating research into policy and management scenarios to improve road safety. Potentially, it promotes accident analysis and related impact assessment across different spatial and time scales and can be considered as enabling technology for data analytics in the accidentology field.

The platform is very flexible, since open source software was used for its development, which facilitates the successive integration of new features and off-the-shelf components. The users are provided with a web interface with models grouped into three categories: delay cost model for assessing the collision impact on travel times (under development), crash rate model to estimate crash frequency for a small urban or rural area, casualty and severity model to predict the number of casualties per accident and its severity. The users can select any of the three categories and apply the related models for simulation. They can also create projects, link them to a specific model, determine the set of predictors and estimate the model's parameters with new observations or with subsamples of the built-in datasets, in order to obtain updated and/or context-specific versions of the selected model (for example, changing from the national scale to a subnational area).

The MAIA toolkit consists of three main core elements (figure 1):

1) a comprehensive and multi-layered integrated database containing information on traffic volumes, speed, fleet composition, accidents as well as other data covering high spatial and temporal resolution. The web application programming interface offers the possibility of adding/removing user selected data to develop up-to-date and/or context-specific models.

2) A central engine including the different mathematical models for both prediction and assessment purposes. The prediction models, in particular, are the focus of this paper.

3) A visualization layer with useful options to visualize both inputs (from the database) and outputs (from the central engine). The visualization tool and its spatial analysis capabilities are based on GIS type tools.
The MAIA web interface contains several interactive buttons, each dedicated to a function. The main functions already included are as follows: *My datasets*, which connects to existing databases; *Input*, to import new data; *Pre-process*, which provides a table format visualization and statistical analysis tools; *Models*, to invoke the available accident prediction models and finally *Projects*, containing two sub-sections, namely *PRJ-variables* and *Results*. The latter two are better represented in figure 2 and 3 respectively.

In particular, figure 2 displays the current toolkit version with regard to the input setting session of the casualty and severity model function, where the user can define a simulation scenario in terms of a specific combination of several roadway and context variables’ values (speed limit, junction type, main road class, day of week and time of day, weather conditions, presence of hazards on road, etc.). Figure 3, instead, on the right-hand side, shows the output of a simulation with the available casualty and severity models. In particular, at the top, a line plot illustrates how the probability of occurrence changes as the number of casualties per collision increases; at the bottom, the expected number of casualties (weighted average of all possible amounts of casualties, with weights equal to the corresponding likelihoods) is presented, along with the probabilities for every possible level of accident severity (slight: at least one slightly injured individual; serious: at least one seriously injured person; fatal: at least one death).

As mentioned previously, a powerful feature was added, that is the ability for the MAIA platform to estimate the accident prediction models’ coefficients on its own. A coefficient determines the impact magnitude of the related predictor (e.g. speed limit) on the response variable of interest (e.g. probability of a serious crash). Hence, the toolkit is able to generalize the mathematical framework of each model taking its parameters as unknown and estimate these with new data. This implies flexibility and space scalability: in fact, the models’ coefficients can be adjusted over time if structural changes occur (e.g. ways police assign injuries to serious and slight classes) and new context-specific models can be developed for those areas where collision phenomena follow anomalous patterns.
Figure 2. Example of input variable setting within the MAIA platform
Figure 3. Example of simulation outcome within the MAIA platform

![Graph showing the relationship between number of casualties and probability of occurrence. The graph displays a line with corresponding values for different casualty categories, such as expected number of casualties and their respective probabilities.]
III. DEVELOPMENT AND SELECTION OF PREDICTION MODELS FOR THE TOOLKIT

As stated above, the set of prediction models embedded in the MAIA toolkit derives from comparing more than 300 models from both the statistical parametric and machine learning domain. All main dimensions of collision modelling were covered: collision frequency at a disaggregate census level (Lower Layer Super Output Area or LSOA), number of casualties per collision and crash severity at the most disaggregate level (road link/junction).

The above two modelling domains were deeply explored. In particular, within the statistics area, count and multinomial econometric models were tested for collision/casualty occurrence forecasting and severity classification, respectively. As concerns the machine learning area, for all accident analysis dimensions, the artificial neural network framework was employed, since it has been gaining wide interest as data mining tool over the last decades. Moreover, the ANNs, besides being evaluated as stand-alone prediction tools, were examined also as components of ensemble models. Ensembling (or pooling) is a novel methodology in the forecasting science and is basically a multi-model approach that combines the predictions of different models to improve accuracy.

A. Methodological issues: problem definition, selection of predictors and data sources, model validation

The problem under investigation was addressed with a multi-step approach (figure 4):

1. Prediction of the number of road collisions per year;
2. Estimation of the probability of non-injury versus injury road collisions, so as to split the predicted number of crashes by the type of impact (only damages for vehicles versus casualties), and forecast of the number of casualties per collision;
3. Estimation of the probability of each severity level, so as to split the predicted number of accidents causing casualties among three possibilities: at least one slightly injured individual, at least one seriously injured person, at least one death.

As to the estimation of non-injury versus injury accident risks, due to the limited amount of data on non-injury crashes available at present, this part of the modelling approach is still in progress and only the model to assess the number of casualties per collision could have been developed.

Figure 4. Multi-step approach for the accident prediction problem

Notes: No Casualty: only damages for vehicles; Slight Severity: at least one slightly injured person; Serious Severity: at least one seriously injured person; Fatal Severity: at least one dead person.
In more detail, 32,844 records of collision annual frequencies (2015) for the Lower Layer Super Output Areas in England and related potential predictors - characterising the LSOA land use and road traffic, along with its population profile in terms of density, gender, age and deprivation - were analyzed and used for collision frequency modelling. Casualty and severity modelling, instead, was based on the STATS19 database, an official set of observations mainly pertaining to collision circumstances across the United Kingdom (specifically England and Wales). In particular, 140,056 records of 2015 STATS19 data were employed to model casualty occurrence and accident severity as functions of the following set of variables: traffic; speed limit; day of week and time; main road class; junction type, if the accident happens at an intersection (roundabout, crossroads, etc.); presence and type of pedestrian crossing facility (zebra crossing, footbridge or subway, etc.); weather conditions; special conditions at site (traffic signal out, roadworks, etc.); carriageway hazards (vehicle load on road, previous collision at the same site, etc.).

To evaluate the prediction accuracy of each model, an appropriate method is to analyze and compare the actual (from the real data) and fitted (estimated by the models) relative frequency\(^1\) for every observed value of the dependent variable, in relation to a time interval different to that considered for model estimations (Cameron and Trivedi, 2005). This means, for example, comparing the percentage of real cases of serious accidents, in a testing year across the UK, with that estimated by the relevant model and check how close the prediction is to the real life.

The use of the above accuracy metric has highlighted that the statistical models - specifically, a collision rate negative binomial model, a casualty Poisson model and a severity ordered Probit model - perform better than the machine learning alternative methods, at least if compared with artificial neural networks when these are employed as stand-alone prediction tools. On the contrary, when the ANNs are combined to form ensembles of models, in very few cases, they perform a bit better.

\[\text{Figure 5. Validation of the model to predict the number of road crashes per LSOA}\]

\(^{1}\text{Number of cases/total of observations.}\)
Based on a set of data different to that employed for model estimation, figures 5, 6 and 7 illustrate the validation process outcome for each of the three selected statistical models: in detail, for every value of the dependent variable, the simulated relative frequency is compared against the observed one. A satisfactory degree of forecasting accuracy emerges from model testing.

As anticipated, non-parametric and ensemble models were built and compared with the parametric ones, in relation to a test sub-sample (30 per cent of the 2015 database), for each of the accident aspects investigated (crash occurrence, number of casualties per collision and severity). In particular, for every value of the considered response variable, the comparison was based on the average percent difference between the observed relative frequency and its simulation (mean absolute percent error or MAPE).

In the crash occurrence case, the parametric approach (negative binomial model) performed better at simulating the occurrence of collisions across the LSOAs, if the number of accidents is in the 0-5 range (inclusive); whereas, beyond the 5 collisions per LSOA threshold, the non-parametric approach (ensemble of neural networks) turned out to be more accurate. However, overall the non-parametric method is a bit superior: its MAPE is 4.68 per cent against a MAPE of 5.48 per cent of the negative binomial model.
As to the number of casualties per crash, the parametric approach (truncated Poisson model) obtained better estimates for the first four levels (1-4 injuries per accident), which anyway accounted for 99 per cent of the test set of observations: the truncated Poisson average MAPE was 29 per cent against a value of 52-53 per cent of the neural models.

In the end, as regards accident severity, the parametric alternative (ordered Probit model) proved the best at forecasting the frequency of fatal and slight events (with MAPEs equal to, respectively, 48 per cent and 87 per cent of those for the best non-parametric model), while the frequency of serious collisions was best predicted by an ensemble of neural networks, whose mean absolute percent error was about 58 per cent of that calculated for the parametric model.

B. Models’ strengths and weaknesses

Although the statistical approach proved considerable accuracy at national level, as demonstrated in Figures 5-7, it revealed less effective in those contexts where road collision phenomena turn out to be exceptional, thus moving away from the mean behaviour on a national scale. In line with recent and seminal advancements in the relevant research field (Alikhani et al., 2013; Catalano and Galatioto, 2017; Sohn and Lee, 2003), a solution could be a self-managing model framework (metamodel). The proposed Metamodel will enable, for each specific combination of input variables, the selection of the most suitable option within a set of alternative collision prediction models, developed for a wide spectrum of situations. In this way, when unusual collision risk factors occur in a certain area, the proposed approach could select an available forecasting model that should have been designed for a cluster of similar areas where that set of factors is not unusual.

IV. ROAD COLLISION IMPACT ASSESSMENT TOOL

This section focuses on the description of a novel and more accurate impact assessment method to evaluate road collision-associated impacts in terms of travel time delays. The analysis was based on data about traffic volumes and speed, as well as road collision and street work temporal and spatial information. In more detail, the data employed derive from several sources: MIDAS (Traffic volumes and speed on the primary road network), ITN OS (road and infrastructure GIS layers), STATS19 (national database of injury road accidents) and Highways England (primary road injury and non-injury road accidents).

The new method can provide an accurate assessment of the delay, as total or individual vehicle time delay due to road collisions. Furthermore, it was developed to be highly transferable, with a view to making it reusable also for other types of disruption events, such as street works and breakdowns.

The development process was based on two initial phases: a temporal analysis stage to examine the time series of traffic data (speed, flow, etc.) and identify typical profiles and anomalies in the traffic behaviour (outliers), to be compared at a 15 minute resolution; a spatial analysis step to reconcile the output from site-specific on street traffic sensors (MIDAS) with the national Integrated Transport Network (ITN) link-based dataset. This resulted in a coherent and as much continuous as possible network with links associated with traffic data.

Then the available information on road collisions (from STATS19 and Highways England, which provides also non-injury collision data) was used to estimate the impact in terms of travel time delay due to individual events. It is important to note that, since the temporal analysis phase has identified anomalies (outliers) independently of the relative causes, this method can provide, as a by-product, the total impact in terms of delay from non-recurrent congestion on the monitored transport network.

The assessment was performed within an appropriate radius of influence (up to 25 km from the site of the collision) to capture anomalies around the event and not only along the main corridor affected. It was also tested using a junction-to-junction (or main node-to-main node) approach, so as to guarantee transferability to linear events such as street works.

The resulting impact assessment tool is currently based on Excel and the outputs of the analysis can be displayed and filtered by different variables. The following figure illustrates the power and usability of the method.
The series of symbols in Figure 8 should be exploited by the reader to identify different types of road accident and events. For example, the symbol means that, in a specific time and date, an accident reported by the STATS19 source has occurred; while the symbol refers to the Highways England dataset, in which accidents are associated to duration values: this means that the considered symbol is reported for every time step of 15 minutes in which the accident has potentially caused an impact.

A. Analysis of road collision impact on travel time

In Figure 9, a road collision event is assessed using the impact analysis tool. From the symbols, it is clear that an accident, registered in the STATS19 database, happened in the 18:45-19:00 interval and caused a significant delay wave (measured in vehicle-hours), as the series of horizontal histograms and associated numeric values shows for a 5 km radius of influence. Observing Figure 9, there does not seem to be any other collision reported in the previous few hours or after the last delay registered.

Figure 10 extends the impact analysis of the above accident event to a set of distance bands of influence (ranging from 5 km to 25 km) on a 15-minute step basis. Time savings and delays are calculated for an eight hour time window (from 15:00 to 24:00).
The impact assessment tool has also other functions allowing, for example, the analyst to quantify accident-related effects on travel time by direction and type of road, including “other roads” like slip roads, as represented in the summary of an event impact and its temporal-spatial evolution showed in figure 11.
B. Impact assessment tool's strengths and weaknesses

The above method for impact analysis showed robustness and very promising results in capturing and quantifying both negative effects (delays) and benefits (savings) associated to known disruption events (namely road collisions reported by independent sources) as well as unknown events, thus giving a full picture of the impact from non-recurrent congestion. Notwithstanding, the identification of the temporal and spatial extent of the event (figure 11) is still subject to a degree of manual scrutiny and is, therefore, expected to get mostly automated in the future through the application of machine learning techniques.

Finally, the impact assessment method described was tested mainly on the primary road network, with the consequence of neglecting some types of impact such as, for example, re-routing traffic using alternative roads outside the primary road network. This, however, is currently under investigation and it will probably be possible to assess and include re-routing effects by using area wide data (e.g. link-based speed data).

CONCLUSION AND FUTURE STEPS

This paper presented a set of models for road crash prediction alongside the description of an innovative web-based platform for road safety policy and management simulation, the MAIA (Models and methods for collision prediction and Impact Assessment) toolkit. In the first instance, the MAIA toolkit has been designed for the United Kingdom.

The forecasting models incorporated into the MAIA platform cover all main dimensions of road collision modelling: crash frequency, casualty occurrence and severity. These models derived from comparing the latest developments of machine learning (non-parametric domain) to econometric methods (parametric domain).

The modelling work has found out that the statistical parametric approach outperforms the non-parametric one, at least if it is compared to artificial neural networks as stand-alone models. If, instead, these are combined with ensemble techniques, in few cases, they perform a bit better than their parametric counterparts. Hence, three microeconometric models - a collision rate negative binomial model, a casualty Poisson model and a severity ordered Probit model - were chosen to simulate the main dimensions of road collision phenomena, based on a comparative analysis of more than 300 models.

A powerful feature has been added to the MAIA toolkit in the late stage of the research, that is the ability to estimate the three above statistical models on its own. This means the possibility of updating models’ coefficients over time, if structural changes occur, along with space scalability.

Although parametric methods proved very good performance at national level, they revealed less effective in those contexts where road collision phenomena follow rare patterns.

The toolkit component for the assessment of collision impact on travel times showed the ability to measure traffic congestion effects for the primary road network (Motorways and A-type roads). Throughout the testing phase, the maximum distance chosen (25 km from the reported location of the event) performed well.

In quantitative terms, it was observed that even one single fatal crash can cause delays equivalent to 2 months of impact from non-extreme accidents in the same section, and road collisions effects on the primary road network section studied accounted for up to 60 per cent of the overall non-recurrent congestion.

During the analysis, a fundamental role was played by the availability of different but complementary datasets (STATS19 and Highways England data, along with information on street works), and their integration was beneficial for the overall assessment and avoiding misinterpretation.

In the end, the results achieved are of potential interest for the Asia-Pacific region, as, within this area, sensitivity to road safety issues has been growing significantly since a web regional network was created to promote the exchange of best practices and expert knowledge amongst governments.
and practitioners. In more detail, a certain degree of harmonization in road accident data production within the region could be the basis for the evolution of the above web network into a road safety decision-making support platform. The MAIA project could be, on the one hand, a paradigm for such a progress, on the other hand, the starting point towards the development of the web-based road safety decision support concept. In fact, a system of accident prediction tools could be integrated into the Asia-Pacific web network as a MAIA-like application, but the high variability of collision phenomena inside the region could lead, beyond the MAIA experience, to a forecasting model framework very effective even when faced with anomalous combinations of accident risk factors.

Further research will explore the benefit of a clustering-based multi-model approach for the accurate prediction of unusual manifestations of the phenomenon (e.g. extreme collision events). Moreover, other potentially explanatory variables will be tested, such as specific road design attributes (road curvature, road width, etc.) and driver as well as vehicle-related predictors (age, driver’s gender, vehicle type, etc.); the authors also intend to experiment other machine learning methods as accident simulation tools.

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ROLE OF INTELLIGENT TRANSPORT SYSTEMS (ITS) APPLICATIONS IN THE UPTAKE OF MOBILITY ON DEMAND SERVICES

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ABSTRACT
Flexible demand mobility services and shared mobility are presented as the way forward to achieve Mobility as a Service. Nowadays, an Intelligent Transport Systems application in users’ devices is as little as it takes for an operator to launch a service. However, mobility services companies operate in a way that is disruptive and often not sustainable at scale, entering in direct competition with mass transit. They follow a process of trial and error in the attempt to attract demand. This paper focuses on the introduction of a seamless, integrated and easy to use demand responsive transit, thanks to the use of a mobile applications which allows access to the service in integration with existing bus services. The evaluation of the ITS flexible service is carried out using an Agent Based Model, which uses disaggregated data, including those coming from the mobile application, to deliver a comprehensive understanding of travel patterns. The tool is ideal for regeneration and expansion areas where very little data is available which is of great interest for many Asia-Pacific growing cities. Demand is identified using anonymized and aggregated Mobile Phone Network Data (MND), which inform the end-to-end user journeys in the model. Results from the Innovate UK funded project “Mobility on Demand Laboratory Environment” demonstrate that a data-driven approach is able to identify demand for mobility services ahead of the launch. The platform is designed to facilitate real-world deployment in integration with existing mass transit. Also, local authorities can benefit from the data-driven approach, which can be transferred to other geographies where transport data is insufficient to assess the introduction of new mobility services.

Keywords: mobile application, demand-responsive transit, agent-based modelling, Mobile Phone Network Data, multimodal public transport, end-to-end user journeys

I. INTRODUCTION
Flexible demand mobility services and shared mobility are presented as the way forward to achieve Mobility as a Service (MaaS). However, the introduction of ride sharing mobility services in urban areas is challenging the balance between private and public transport. The use of mobile applications has enabled private operators to easily reach the customers, collect data and learn from the usage of the service. Most of the time the operator works in isolation, which is disruptive and not sustainable at scale. Mobility services operators don’t follow a specific strategy prior to activating a service but undergo a process of trial and error in the attempt to attract demand, however, they could provide a useful asset for the public transport sector, extending the catchment area of services and acting as feeder for the fixed scheduled public transport.

With the introduction of MaaS it is even easier to integrate seamlessly the tickets and allow the user to have a multimodal door to door service without the need to use their own private car. Data collected from the use of the service can improve the service itself in the operation but not during the planning phase ahead of the launch. Many data currently collected for other purposes and data from local authorities could help in planning a flexible mobility service which works in cooperation with fixed scheduled public transport services.

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However, many strategic modelling tools are designed to determine traffic flows from private cars and public transport but are not fit for the purpose to represent the functionality of a demand responsive transit. Moreover, they’re mainly trip based, which makes difficult to understand the end-to-end users journey and identify potential customers for mobility services providers. Using these tools, it is impossible to predict how a Demand Responsive Transit (DRT) can contribute to improve the level of service to the users or quantify first mile and last mile service. Currently operators collect data from their services, hence at micro scale but don’t focus on a strategic planning at city level or even beyond.

This paper focuses on how to use these datasets to inform an agent-based model (ABM) to represent city wide commuting patterns, identify demand and handle disaggregated data, such as MND, public transport data, telematics and data feeds on usage of the DRT. Moreover, this platform is built on an open tool and the process used to build the synthetics population can be transferred to many other geographies which do not have historical data (i.e. expansion areas, regeneration areas).

The following sections of the paper report on a literature on DRT and MaaS applications in the Asia-Pacific area, how the planning of the operation is considered and if there was any direct learning for policy makers. The section that follows sets out the design of the ABM model developed for the case study of Greater Bristol in UK, followed by a summary of the simulations and results achieved. The paper concludes with the implications, the results achieved in the operations of the DRT services introduced and some considerations on limitations and how to improve further the model.

II. Literature review on Demand Responsive Transit (DRT)

The DRT or mobility on demand services are now used in urban areas to cover first mile and last mile leg in longer journeys. With the introduction of Intelligent Transport Systems and smart technologies the accessibility of these services to users have been increasingly seamless and integrated with other public transport services. However, the DRT was associated in the past with low demand areas which required an ad hoc service in order to provide social inclusion in rural areas (Mulley et al., 2009). Also, Wang et al. (2018) found out that DRT covers the needs of disabled, users travelling for work, or live in less densely populated areas.

However, Davison et al. (2014) in a review highlighted that when a DRT service is launched in developing countries it is going to be mainly market and profit driven; while when launched in developed countries such opportunities have been restricted to niche markets or priority has been given to social inclusion or in supporting specific type of users. This found confirmation in the recent interest of the automotive industry in the Asia to apply disruptive innovations linked to new approaches to mobility. Future Centre Asia, for example, was funded by the Volkswagen Group to understand how Chinese and Asian market are welcoming these changes in mobility and how insights from data automatically collected can replace local knowledge3.

There is a focus in adapting the future mobility services to the needs of customers who tend to be younger, digitally connected and with an open mind to new solutions. Other automotive groups are concentrated instead in providing services attached to shopping and leisure facilities, creating alliance with shopping malls. Customers in Tokyo and in Hong Kong can benefit from a premium service, Audi on demand4. And they plan to scale up to China. They tailor the service on local factors and customer requirements in a specific market to customize the service according to the locations where it is running (i.e. a luxury residential complex) and the limitations of this location (i.e. lack of parking or parking restrictions).

Flexible transport can take many different forms. In the FLIPPER Project,5 Flexible Transport Services and ICT platform for Eco-Mobility in urban and rural European areas, (Enoch et al, 2004) a detailed description of 70 schemes around the world is available. DRT is considered a hybrid transport service options offering user-generated routes but for a higher fare than fixed scheduled mass transit.

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5 http://www.interreg4cflipper.eu (accessed 22/10/2018)
Frei et al. (2017) shown that mobility service operators, such as Uber and Lyft, offer a competing form of taxi service for many travellers; while preliminary research has shown they may complement transit service in underserved areas, however long-term impacts are not yet clear (Shared Use Mobility Center, 2016). Other mobile applications for hailing taxicabs are also available, and the regulatory definitions and policies to distinguish traditional ride-sharing, taxi/livery services, and public transport are evolving (Yousef, 2014).

Evidence (Daniels et al., 2010) shows that flexible transport services are not used as widely in Asia-Pacific as they are in other countries including the UK and Europe, despite their potential to increase accessibility and improve social inclusion where conventional public transport services are not viable. Barriers were grouped into five themes: (i) policy, legislation and regulatory environment; (ii) economic issues of funding, costs and fares; (iii) operational issues of fleet and vehicles; (iv) attitudes, culture and perceptions amongst stakeholders; and (v) barriers of information and education about flexible transport services. Mulley et al. (2012) have concluded that in the Australian region it is the very flexibility of DRT - in terms of service structuring, service organization, and service delivery options - that represents their greatest asset in meeting the cost-effectiveness challenge.

Improving public transport has long been argued as an alternative to car use in many western countries and substantial funds spent on improving both quantity and quality of bus and rail services (Banister, 2008; Chapman, 2007; and Sharaby et al., 2012). Attitude about the quality of public transport services is a key issue on the perception of users' satisfaction and actual use (Friman et al., 2009; and Shifman et al., 2008). However, in developing countries, most trips are already conducted by public transport, but many services are informal and unregulated and often compete sometimes aggressively against the better organized and safer formal public transport modes (Cervero et al., 2007). These informal modes, in some cases falling within the remit of DRT, often clog city centres generating congestion as well as severe environmental problems and safety hazards. This is a challenge for the future of urban mobility that needs to be carefully addressed by decision makers.

Effective road-based public transport is central to economic growth of developing cities. For the majority of residents in developing countries, road-based public transport (bus and paratransit) is the only mean to access employment, education, and public services. In medium and large developing cities, such destinations are beyond viable walking and cycling distances while vast numbers of individuals have limited access to cars (Pojani et al., 2016). Unfortunately, the current state of road-based public transport services in many developing cities does not serve the mobility needs of the population adequately. Formal bus services are often unreliable, inconvenient, uncomfortable, or even dangerous. Informal paratransit services, while providing benefits including on-demand mobility for the transit-dependent, jobs for low-skilled workers, and service coverage in areas devoid of formal transit supply, carry major costs, such as increased traffic congestion, air and noise pollution and traffic accidents (Cervero et al., 2007).

The Role of Technology

What makes the difference in today’s services is the use of telematics-based Flexible Demand Services which have the scope to bring public transport closer to the flexibility and convenience of private transport, whilst retaining a fare structure more in line with public transport journeys, as opposed to the most flexible – but costly – private hire and taxis (Mulley et al., 2009).

At a simplistic level we know there are many buses and other vehicles out there that remain underutilized. People want to get from A to B but are unsure where these buses are parked and believe they only operate on fixed routes. The solution that connects these elements together is technology. If people have a flexible way of knowing or demanding this travel, then DRT can provide the solution. DRT can make a significant contribution to the creation of better, more integrated local passenger transport networks that can meet more needs, being the first and best choice for making a journey (CTA, 2017).

The role of technology in the public transport sector should be also taken into account for future plan. For example, in the Malaysia National Land Public Transport Master Plan (Land Public Transport Commission, 2014) there is an ambitious objective to achieve a land public transport modal share of 40 per cent in urban areas, as well as enhance access in underserved rural areas, while increasing connectivity between locations. Actions are on the right direction, however with a digital population fast
growing, achieving the NLPTMP objectives without considering a centralized policy embedding DRT and its flexible approach may result in difficulty to achieve the goal.

Modelling Applications

A previous study demonstrated that a minibus service can offer a greater accessibility in residential areas, thus increasing bus patronage (Ambrosino et al., 2016). However, costs for the bus companies are too high to be sustainable. As pointed out by Navidi et al. (2018), fixed scheduled public transport is no longer functional to satisfy the demand for travel. Real time information and computational power make it possible to use new generation tools. His results demonstrated replacing conventional public transport with demand responsive transport will improve the mobility by decreasing the perceived travel time by passengers without any extra cost.

Other studies explored how the introduction of MaaS is eliminating the traditional division between collective transport and individual private transport. In recent years, public transport services have been complemented either by DRT services, which serve a dispersed demand or by Flexible Transport Services (FTS), which focus on a complete satisfaction of user needs and can be on a not shared or shared basis. Whilst business models have been explored in many EU Countries (Bell et al., 2012; and Franco et al., 2012) operations are not standardized yet and different approaches are adopted.

To test and explore the efficiency of flexible and shared service, modelling can help and support in identifying those areas that are currently served by inaccessible, unaffordable and inappropriate public transport (Auld et al., 2016). Previous studies tried to tackle the agent-based approach, integrating an ABM, built with UrbanSim platform with a four-stage transport model (Hafezi et al., 2017), highlighting that the proposed approach could support the long-term planning impact. However, the activities generated using the trips from the 4-stage model were used to support a strategic model and evaluate the impact of population growth in urban areas.

Recently, with the increased use of big data source and computational power, ABMs have evolved and now include also microscale modelling tools that can provide an ideal environment to assess flexible shared services. Historically, agent-based models were macroscopic models that provided great level of detail and insights in the demand modelling, especially in representing trip chain. Recent advancement in the ABM sector allows not only use of traditional demographics and land use data, but also inclusion of new disaggregated data source (Ho et al., 2018). The agent-based model represents a wide area at a microscale level, which was not possible to achieve in the past and it is still not possible with traditional traffic microsimulation software (Balmer et al., 2004).

Synthetic population in ABM was built using census data (Balmer, 2004) and an activity-based models were used to generate travel patterns with socio demographics characteristics often coming from large household travel diary surveys. Auld (Alexander et al., 2015) developed a new comprehensive pattern recognition modelling framework that leveraged activity data to derive clusters of homogeneous daily activity patterns (Meister et al., 2010). Based on the socio-demographic characteristics of individuals they identified which cluster individuals belonged to, and predicted various information related to their activities, such as start time, duration, travel distance, and travel mode, for use in agent-based travel demand modelling.

In the last decades, the shift from using typically aggregated data to more detailed, individual based, complex data (e.g. GPS tracking) and the continuously growing computer performance on fixed price level lead to the possibility of using microscopic models for large scale planning regions (Wang et al., 2018). An open software platform, MatSim, developed by the Technische Universität of Berlin and the Swiss Federal Institute of Technology in Zurich (ETH Zurich) has been used to explore changes in the transport systems and the uptake of new technologies. MatSim is a multi-agent micro-simulation model. In MATSim each modelled agent (person, vehicle, etc) contains its individual settings, made of demographic information and the daily plan. The sum of all physical agents reflects the statistically representative demographics of the region. The demand is modelled and optimized individually for each

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agent, not only for some parts of the demand like departure time and route choice, but as a complete temporal dynamic description of the daily demand of each agent.

The Future Cities Laboratory is a transdisciplinary research centre focused on urban sustainability, located in Singapore, established by ETH Zurich and the Singapore’s National Research Foundation. A MATSim complete model for Singapore was built to identify initial demand modelling based on diverse sources of data, such as the Household Interview, Travel Surveys shared by Land Transport Authority (LTA), land use information from Urban Redevelopment Authority, NAVTEQ (base electronic navigable maps) and diverse web resources. The simulation covers both public and private transport and their interactions. However, they claim that no immediate relevance to policy and planning has been identified (Banister, 2008).

Finally, a Last-mile Evacuation simulation was developed for the Indonesian City of Padang, which faces a high risk of being hit by a tsunami. A realistic simulation of the evacuation process helps to give an estimate of the evacuation time, to detect bottlenecks in advance and to identify highly endangered areas, where a vertical evacuation seems the only way.

Research gaps addressed

A main issue highlighted above, especially in the Asia-Pacific regions, is the high probability of disruptive consequences for the Public Transport market by introducing new unregulated private Demand Responsive Transit (DRT) services which can decrease the quality of living in highly densely populated areas.

Many authors have used the ABM approach to visualize demand from users, but the application on DRT and new mobility services is limited. The integration with fixed scheduled public transport will relieve congestion and improve air quality in the urban areas. The ABM, in particular, has the ability to replicate and weight user requirements understanding their travel pattern.

Another major gap noted in the literature is the lack in standardization in the model used but also in the type of data used to build a synthetic population. The choice of utilising MND is quite unique and allows for a rapid collection of data, which reflect the actual status quo and is not dependent by small samples which can potentially be biased. MND are continuously collected and, even if are anonymized and aggregated, can still reveal important insights in the end-to-end user journey. Many previous works on DRT are still based on Census information but also are linked to legacy format of transport models where all demand data is associated to origin destination matrices which are trips-based.

III. The Mobility on Demand Laboratory Environment Project

In the Innovate UK funded Mobility on Demand Laboratory Environment (MODLE) project we are demonstrating that a data-driven approach is able to identify demand and model travel patterns. The MODLE platform has at its core an agent-based model which takes into account commuting patterns and supports the operation of an SME which delivers mobility on demand services in areas with inadequate PT services.

The choice of using an ABM has been led by the capability of representing end-to-end users’ journeys using daily activities rather than disconnected trips. Moreover, a flexible demand mobility service cannot be represented as a traditional private hire service because there is no route or predefined timetable which is fully representing the operation of the service.

The ABM has been built using the open source platform MatSim, a strategic multi-agent micro-simulation model, based on a synthetic population which reflects real choice and needs from users. Mobility services are easy to activate and can adapt to the need of users but how to identify demand in advance without incurring in local bias is a challenge.

In the MODLE project, the service prior of the start of the trial was modelled. Performance data and users’ requirements are collected using a mobile phone app developed by the company ESOTERIX, who is operating the DRT services. Data collected are then used to improve the simulation of the service or to change the service itself to achieve a better performance.
The area of interest is a regeneration area in the north of Bristol (UK), where lots of industrial park and distribution centres are located. There is a poor network design, legacy of previous land use and a high level of congestion. In North Bristol, up to 75 per cent of employees commute in single occupancy vehicles, with very little alternatives and accessibility option for commuting. Moreover, it is expected an increase of 14,000 new jobs in the area by 2030.

Poor accessibility, the provision of public transport mostly unaffordable, inappropriate to satisfy their needs and the increase in congestion and lack of parking led to unsustainable growth and poor quality of life for commuters, leaving jobs unfulfilled.

To study the introduction of DRTs is pivotal to have up to date data which reflects the actual situation. Census was collected in 2011 and other source of data are limited to small samples which are not normally collected specifically for the area.

In the MODLE simulation, demand and travel behaviours are informed by MND, which reveals real patterns from users (OD matrices and trip chains).

To best inform the service, MND are at a higher spatial granularity in the area of interest for the service and two datasets have been analyzed: trip chain information and trip-based origin destination matrices.

The main aim of the MODLE agent-based model is to assess the impacts of the proposed ride-sharing service on a multimodal network; to understand how demand model will change once the service is active; which modal shift can be achieved, and what is the impact on the public transport services operating in the same area. Other impacts, such as improvement in accessibility to employment and services, increased number of longer journeys made sustainably, reduction of congestion will be assessed.

In figure 1, a visual representation of the model for Greater Bristol in UK, with Bristol City in the middle and the city of Bath on the right-hand side. The model extends for the entire region of the South West of England, since many users were commuting in Avonmouth, in the north-west corner of Bristol, from far away.

The SeverNet Buzz Flyer is an e-hailing minibus service that will improve mobility in the area of Avonmouth with poor accessibility and strongly relying on private cars. The catchment area of the service is north of the river Avon and north of the A420 in the east, however, the model extends to Greater Bristol, which comprises Bristol City, South Gloucestershire, North Somerset, Bath and North-East Somerset (see figure 1) to take into account all the commuting patterns.

**Figure 1. Greater Bristol MatSIM Model extension**
IV. THE MODEL MATSIM MODEL

METHODOLOGY

The agent-based model was built using the open source software MatSim and publicly available data have been used to populate the static information in the software. As described in figure 2, the model includes a multimodal public transport network. The network and facilities have been imported using Open Street Map. The public transport network was imported from the publicly available Traveline Database\(^7\) which included 340 bus services, with routes and timetable. Bus stops and train stations are loaded from the National Public Transport Access Nodes (NaPTAN\(^8\)) database from the UK Department for Transport [35]. Rail services have been downloaded from Association of Train Operating Companies (ATOC\(^9\)) [36]. Average fares structure was generated looking at First Bus Group fares, who is the main operator in the city of Bristol. This information represents the infrastructure available and the fixed scheduled public transport services currently available and not able to satisfy the demand in the Avonmouth area. The flexible demand service will attract the unsatisfied demand.

Figure 2. Modelling framework

Demand Generation from Mobile Phone Network Data

The users of the service are represented by static agents in the MatSim model. Each of them has a schedule which represents their activity plan over a day. Agents and schedules have been created using anonymized and aggregated Mobile Phone Network Data, created using four weeks of data from a neutral month (March 2016) to represent an average weekly day.

A finer resolution, matching the Lower Super Output Area (LSOAs) in the city of Bristol was used for the Buzz area, whilst Middle Super Output area was used for the Greater Bristol. The aggregated output is a trip-based origin destination matrix, based on data at LSOAs and Lower Super Output Area

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\(^7\) TravelLine Dataset available at https://www.traveline.info/ (accessed 22/07/2018)


(MSOAs) areas. Since MND are collected in a continuous way, the matrix will also include NUTS1\textsuperscript{10} (all areas outside South West of England) and NUTS3 (regions around the area of interest) trips taking into account need for travel outside the area of interest\textsuperscript{11}.

<table>
<thead>
<tr>
<th>Geography</th>
<th>Minimum population</th>
<th>Maximum population</th>
<th>Minimum number of households</th>
<th>Maximum number of households</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSOA</td>
<td>1,000</td>
<td>3,000</td>
<td>400</td>
<td>1,200</td>
</tr>
<tr>
<td>MSOA</td>
<td>5,000</td>
<td>15,000</td>
<td>2,000</td>
<td>6,000</td>
</tr>
</tbody>
</table>

Demographics information (i.e. age, gender and income) are collected from Mobile Phone Network Data as well. This is possible using pay monthly contracts and expansion factors are applied by the network provider directly. Missing information from MND was recollected assuming that the demographics will be aligned with Census trends.

Two datasets have been acquired by the network provider to generate static agents.

The first one is made of trip-based Origin Destination matrices where information on mode of transport and purpose of the trip is known. Only two modes of transport are available: rail and road. Road users are inclusive of drivers and passengers and no distinction can be made between private and public transport users. Static agents are divided in car drivers, car passengers and PT users.

Matrices are available for four-time periods (morning and afternoon peaks, inter peak and off peak) and three trip purposes (home based work, home based other and not home based) which are associated to inbound and outbound trips.

Since trips are not connected between each other, the use of the trip-based dataset generates one agent for each trip in the dataset (1,900,000 agents in total) with increase of computational power. The simulation generated would be useful to understand traffic flows in the network, but it will be unable to deliver a comprehensive understanding of the users’ travel patterns.

The second dataset, also available at LSOA and MSOA areas, maintains trip chains information. The trip chains dataset informs on how many trips are done in a day (from 1 trip up to 12 trips in a day) in any journey from aggregated users. The total number of agents generated with this dataset is 722,752. However, to comply with GDPR regulations, data are further anonymized. Journeys were divided in Return Journeys (starting and finishing in the same zone) and Not-Return journeys. Very little assumptions can be done on the not return journeys, but assumptions have been created for the 68 per cent of journeys which are Return journeys.

Assumptions need to be made to assign a purpose and mode to the trips in the journeys. We have used Structured Query Language (SQL) queries in ArcGIS software to cross reference information from land use and facilities.

Moreover, for the purpose of building activity patterns, each trip chain is associated to more detailed time periods, which gives a higher precision in the temporal distribution of the activities. Each time period is made of three hours and interpeak periods are three, one in the morning (Interpeak1), one in the early afternoon (interpeak 2) and one in the evening (interpeak 3).

Schools and train stations and other facilities have been included in the map to identify the purpose. School runs are identified when trips are made in Interpeak 2. More challenging is to identify trips towards primary schools since they qualify as short trips and generally located within the same census area, hence these trips are not captured in the MND.

\textsuperscript{10} NUTS stands for Nomenclature of Territorial Units for Statistics (NUTS) and is a European standard for Census areas.

\textsuperscript{11} Lower, Middle and Super output areas is the standard adopted by the Office for National Statistics in UK.
To identify purpose of each leg in the trip chain dataset, the following assumptions have been made. For Return trips, starting and finishing in the same location, it is assumed that the trip is home-based. For all intermediate trips, land use mapping was used to identify type of facilities in order to improve the purpose classification. However, since MSOA and LSOA can be quite large it is difficult to identify purpose of a mixed-area (where residential, commercial and industrial facilities are coexisting).

Time when the first trip started and land use, and facilities (school, shopping malls, train stations and Park and Rides) helps in identifying the purpose of each trip in the journey. Manual checking and visualization of the trips has improved the rules for each clusters of trip chain categories.

The implementation of the flexible mobility service

The SeverNet Buzz flyer (13 services and 200 users across different businesses) has been launched in August 2018: the service is available to workers in the companies that registered for the service. When the employer subscribed to the DRT service, users travel for free. Service is also open to occasional users who pay 1.50£. Service is pre-bookable from an online portal, hence route is defined on a daily basis.

To analyze the demand and run the simulations quickly a reduced area at the higher resolution LSOA has been chosen (Figure 3). Running on a reduced size area (Severnet Buzz Flyer catchment)

Total number of agents for the reduced area is 32,902 which represents journeys 22,940 in the trip chain dataset.

Figure 3. SeverNet BUZZ service routes

The BUZZ service is modelled as a private hired bus service in Simulation 2 described in the following paragraph.

A deeper analysis of MND has been carried out to understand in which areas people will be keener to shift to the shared service (usually residential areas in the proximity of the industrial park) and where people will be more likely to use the service as a first mile and last mile service in integration with the fixed scheduled public transport.
At the end of this analysis, the different level of aggregation in the MODLE area (LSOA, MSOA, NUTS1 and NUTS3) also identified travel patterns and distance travelled with many users travelling from outside the region (mostly from London). In figure 4, darker areas represent the zones of origin where is more likely people will be keen to use the service. The map represents a combined index of number of trips generated/attracted and density of population in the zone, but information on the journeys and how their distributed over the day are not given.

For example, looking at trips between Avonmouth and the city centre of Bristol, a high number of trips which were not explained by local knowledge was revealed. Insights from the trip-chain datasets revealed journeys with a high count of trips in a single day, mainly concentrated in the early morning and morning interpeak, which is linked to journeys due to logistics and distribution.

Avonmouth routinely attracts the inbound and outbound journeys to the residential area of Staple Hill and the UWE campus areas of Frenchay and Glenside. Most journeys to and from the industrial area of Severnside come from the South Gloucestershire areas Thornbury South and Alverston, and Patchway. Most journeys to and from Avonmouth are to the Bristol suburbs of Cabbot and Henbury.

For the rail mode, all of the different areas investigated attract the majority of rail trips from NUTS areas. Park and ride trips are also included in the travel counts. The number of inbound and outbound rail journeys in Frenchay is approximately 3.8 times higher than in the other four areas combined.

**Figure 4. Demand for the Buzz service in Avonmouth**

A deeper analysis of MND in the Buzz service has been carried out to understand which areas are where people will be keener to shift to the shared service (usually residential areas in the proximity of the industrial park) and where people will be more likely to use the service as a first mile and last mile service to the fixed scheduled public transport, either bus or rail.

At the end of this analysis, the different level of aggregation in the MODLE area (LSOA, MSOA, NUTS1 and NUTS3) also identified travel patterns and distance travelled, that most people were travelling from outside the region (mostly from London).
Demand in the MatSim model is generated with the creation of static agents, which must fulfil their activities in a timely manner otherwise will be penalized by the model. The scoring they receive will affect the following iteration: a negative score will produce a change of plan in the agents, either a change of routes or schedules in the activities, according to the innovation strategies specified in MatSim:

- ChangeExpBeta, changes between plans with a configured probability (70 per cent)
- ReRoute, searches for alternative routes other than the shortest path (10 per cent)
- SubtourModeChoice, changes mode of transport (10 per cent)
- TimeAllocationMutator, shifts activity end times randomly within a configurable range (10 per cent).

We run several simulations for the purpose to assess different data input to generate the daily plans for the agents. Simulations and the base case scenario have been built to explore the difference between different methods for agents’ generation:

- **Simulation 1**: data input from OD assignment matrices from the Greater Bristol model built with the commercial modelling tool Saturn
- **Simulation 2**: static agents have been generated using anonymized and aggregated Mobile Phone Network Data, using trip-based OD matrices for Road and Rail mode and for 4-time periods
- **Simulation 3**: agents generated using trip-chain dataset and 6-time periods. Enhanced dataset will comprise purpose and mode

V. RESULTS FROM SIMULATIONS

We explored several solutions to understand the potentiality of the data input and the results that can be achieved with different data granularity. The first dataset to be used as input data was the travel to work data segmented in three times periods: Morning, Evening and Interpeak. The activities are home, work, and other. All the agents are employed and contain information about gender and age. The Greater Bristol network is loaded with 352,739 agents traveling by private car and bus. The simulation required two days to run on a machine with 40 CPUs and 200GB of RAM.

In the second simulation, the synthetic population was built using anonymized and aggregated MND to generate static agents and provide information on demographics (gender, age and income) and travel patterns at LSOA for MODLE area or MSOA level for Greater Bristol, using trip-based OD matrices per each mode of transport and per each time period.

This has generated 1.9 million agents, since no trip chain was maintained, leading to a highly congested network. Moreover, MND are only able to provide information on road transport or rail, so any information on how many passengers are in private cars or public transport was missing. Occupancy on public transport was created using the Trip End Model Presentation Program (TEMpro) software from Department from Transport in the UK.

To represent the end-to-end user journey, data input was changed in trip chain dataset for the third simulation. Using the new data input format, the end-to-end user journey is retained, and the number of static agents dropped to 722,000 for the Greater Bristol area.

The run time was reduced creating assumptions on purpose and mode of travel so that many activities were time bounded.

The strategy module used for the scoring mechanism contains the following weights:

- **BestScore**, choose the previous iteration’s plan (80 per cent)
- **ReRoute**, searches for alternative routes other than the shortest path (10 per cent)
- **SubtourModeChoice**, changes mode of transport (10 per cent)
- **TimeAllocationMutator**, shifts activity end times randomly within a configurable range (0 per cent)
The Buzz network was introduced as a fixed route service and defined as private transport publicly available. Several iterations were run to establish the cost of the service and the uptake of the Buzz service when the cost to access is varied.

Results shown a modal shift of 2 per cent from private cars with a 30 per cent increase in the use of public transport services (both rail and bus). This was explained by the fact that people were travelling from other areas and the presence of the DRT has increased the accessibility of the Avonmouth area located in the north of Bristol (UK). Maximum number of people which is attracted by the service is 500 users, which is in line with the growing number of subscription to the service.

CONCLUSION

Mobility on demand services will be extremely useful in future to provide the first/last mile service in a fully connected and integrated transport systems under the Mobility as a service wide vision.

The use of agent-based models (ABMs) is largely unexplored in the transport sector, but with the increase of computational power and data fusion techniques, mobility services operation and mobility on demand can be considered even if no routes and timetables are specified in the model.

This provides local authorities and central governments with a tool that is able to quantify the impact of the introduction of private mobility on demand services and quantify the integration with the mass transit, allowing the reorganization of public transport services which is reducing operational costs on less profitable corridors.

The main focus of this application is to develop an open and accessible tool for consultants, Local Authorities and even operators to assess the potential and associated impacts of the integration with mass transit of Demand Responsive Transit (DRT) with existing or new fixed schedules public transport services. This is particularly of interest for regeneration of urban environments or for rapidly growing cities such as in the case of Asia-Pacific cities region.

The work presented in this paper is part of the Innovate UK funded MODLE project aiming at exploring the introduction of mobility services in areas currently served by inadequate public transport to meet current demand and users’ needs. The case study proposes to model mobility services ahead of the launch using an agent-based model, to identify the demand and assess the performance and impact of the services in corridors of interest for the operators and the Local Authorities. The output of the model is a powerful visualization of users’ travel patterns which highlights bottlenecks and congestion hotspots and specify how many users are going to utilize the new service.

The visualization tool, integrated with the ABMs, is very intuitive to communicate to policy makers and stakeholders from different backgrounds the hotspots and where the pain points are in the road network.

The data-driven approach provides assurance on real travel patterns and commuting habits at a regional scale, which goes beyond the administrative boundaries of strategic transport models and provide a comprehensive picture that takes into account rail and road modes.

Also, the generation of a synthetic population using an activity-based model to generate daily plan for agents using MND is not a standardized process but provided the possibility to explore commuting patterns in areas where historical data were limited due to the change of the activities in the areas. MND are collected continuously by the network providers, hence the data always reflect the actual demand available when the service has to be launched.

Main focus of the model was representing the integration with fixed schedule public transport service (Rail and Road) to demonstrate full integration of public transport with private mobility services. The open platform MatSim used to build the Agent based model was used to model and visualize demand for the proposed flexible demand responsive transit.

Results from simulations show that a higher granularity and trip chain dataset provided better insights of travel patterns and in the number of agents generated by the model. We have compared the
performance of the model using both trip-based and trip-chains dataset and we have found that the trip-chains datasets, which retains information on the sequence of trips over a day, creates a reduction from 2 million trips to 722,000 journeys for the Greater Bristol area. This led to a quicker running time of the model but also to a greater understanding of travel patterns from users and to whether or not to deploy the DRT in an area. The Buzz service simulation highlighted that DRT works better in integration with fixed scheduled public transport services with a 30 per cent increase in patronage and a 2 per cent modal shift from private cars. Different prices were tested for the uptake of the service.

However, further work is needed to identify external factors that might affect the uptake of Mobility on Demand service. This quantitative information can also be considered and specified in agent-based models.

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REFERENCES


APPRAOCH TO PRIORITIZING INTELLIGENT TRANSPORT SYSTEMS (ITS) SERVICES IN DEVELOPING COUNTRIES – THE MONGOLIA CASE

Jaehyun (Jason) So*, Mijeong Kim**, Taehyung Kim***, and Suran Son****

ABSTRACT

This study proposes a systematic approach to prioritizing the selected ITS services, and applies it through a case study in Mongolia. While numerous ITS solutions have been deployed in various forms in many cities and countries, a specific set of ITS solutions must be inevitably selected due to budget constraints. In addition, the selected ITS services should be prioritized by taking their importance and the budget situation into account. This is more critical in developing countries in particular because the budget constraint in developing countries is more severe than that in developed countries. In addition, many developing countries have different situations by regions, and especially population is dense in the capital cities while it is very low in other regions. Thus, the prioritization should also take this regional imbalance into account. With this in mind, this study proposes a methodology for prioritizing ITS services, which is a core of the national ITS master plan. For prioritization, the following five criteria are suggested: i) existence in traffic policies and development plans of the target country, ii) problems and needs identified by the general public, iii) problems and needs identified by transport experts, iv) existing services currently in operation, and v) principal investigators’ engineering judgment based on identified traffic problems and issues. Prioritization is made based on scores, and the total score of each ITS service is finally used to prioritize ITS services. As a result of case study in Mongolia, twenty ITS services were selected and prioritization was made in three stages for two regional separations, respectively. These systematic (i.e. criteria-based evaluation) and hierarchical (i.e. regional separation) features of the proposed methodology for prioritizing ITS services will also provide a useful reference for other developing countries in Asia.

Keywords: intelligent transport systems (ITS), ITS master plan, ITS service prioritization, public needs survey, and developing countries.

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I. INTRODUCTION

Intelligent Transport Systems (ITS) aim to mitigate severe traffic congestion and enhance safety in roadways by monitoring traffic states, providing relevant traffic information to drivers, and responding to any incidents. Conventional traffic solutions such as road construction, traffic calming, and fixed traffic signal timing plans either required abundant resources in the area of budget and labor or had marginal impacts in terms of mobility and safety. On the other hand, ITS has been an effective solution to resolve traffic issues with a relatively lower budget based on advanced sensor, communication, and information technologies. Considering ITS’s efficiency and effectiveness, many countries have established an ITS master plan at the national and regional levels, and thus deployed ITS in their roadways (KICT, 2016).

The national ITS master plan is the first step to introducing ITS in one country, and should be established for an effective ITS deployment in terms of service benefits and budget. The ITS master plan generally provides ITS implementation plans by stage (i.e., short-term and long-terms plans), including selected ITS services and the following system designs, required finance, and any legal/regulatory issues to be resolved. Particularly, selecting and prioritizing the ITS services is a focal point of the ITS master plan because the subsequent tasks such as system design, finance, legal/regulatory amendment are supposed to be provided based on the prioritized ITS services deployment plan. In previous decades, national ITS master plans have mostly been established by developed countries, in recent years, many developing countries have also attempted to develop their own master plan (MOLIT, 2011). Developing an effective national ITS master plan is particularly important for developing countries because the budget constraint in the developing countries is generally more severe than in developed countries. That is, for developing countries the ITS services should be more thoroughly contemplated and selected when the national ITS master plan is being considered.

The conventional approaches of ITS services prioritization have not been standardized or articulately defined. In fact, ITS services prioritization has often been based on only the principal investigators’ engineering judgment without enough explanation. The methodology proposed in this study aims to minimize the use of the principal investigator’s engineering judgment, which might be subjective, so that the ITS services can be objectively and systematically prioritized considering many aspects such as the results of the needs survey, inclusion of the country’s plans, and the investigators’ understanding of the country’s status and issues to be resolved.

With this in mind, this study aims to develop a methodology for selecting and prioritizing ITS services by stage considering the traffic issues and needs. To select and prioritize ITS services, the candidates need to be evaluated in terms of their significance including the regional traffic issues, and their urgency on the regional-social needs. Accordingly, the objective of this study is to develop a methodology for an evaluation of the significance and urgency of the candidates of ITS services, and ultimately to develop a methodology for selecting and prioritizing ITS services based on the regional traffic issues and needs.

To this end, this study uses a case study of Mongolia; thus, the preliminary analysis results of Mongolia are provided, and the ITS services prioritization results are also provided with regard to the ITS services selected for the Mongolian road and traffic networks. To consider the regional characteristics of the case study country (specifically, that 40 per cent of its total population lives in less than 1 per cent of the total land area), the analysis including a needs survey and service selection and prioritization are conducted separately for the capital city (Ulaanbaatar) and the other areas of Mongolia.

This hierarchical approach will provide a great reference for the other developing countries which have similar demographic characteristics. Furthermore, this study suggests a systematic approach in selecting and prioritizing ITS services using the scoring criteria and evaluations, ultimately so that other developing countries can readily apply this methodology when they develop their ITS master plan.
II. LITERATURE REVIEW

ITS master plans have been established by many countries and cities around the world because this is the first step of deploying ITS services and systems in a specific region. However, not many ITS master plan projects have utilized a systematic approach to prioritize ITS services, and a needs survey and a review on existing plans have been used as major approaches to prioritize the ITS services and systems. As a result of reviewing the existing ITS master plan practices, which are summarized in Table 1, the following methods were used in these existing cases in order to prioritize ITS services: 1) analyzing traffic situations, 2) reviewing existing national/regional plans, and 3) a needs survey. Although these practices have attempted to introduce some procedures to identify the needs and problems of subject regions, the prioritization methods have not been applied with an articulated methodology or procedure, and rather the prioritization has been finally determined by the principle investigators’ engineering judgement only in consideration of the understandings on subject regions. Therefore, there was no science involved in the prioritization of ITS services, and it was highly likely that decisions on ITS services prioritization involved subjective judgment by decision makers. Furthermore, there was no consideration of regional separation when selecting ITS services while this is important in developing countries where population densities are imbalanced by regions. Therefore, our review of existing ITS master plan practices identified a need to enhance the ITS services prioritization and develop a systematic method in prioritizing the ITS services. In addition, the methodology of the ITS services prioritization should flexibly take into account regional characteristics (e.g. the road and traffic characteristics are heterogeneous according to the region, a feature found in many developing countries).

Table 1. Summary of ITS service prioritization practices

<table>
<thead>
<tr>
<th>Area/Country</th>
<th>Service prioritization criteria in consideration</th>
</tr>
</thead>
</table>
| Lima, Peru (KICT, 2016) | - Current traffic status and issues.  
- National policies on roads and traffic. |
| Czech Republic (MOT, 2016) | - Current traffic status and issues (roads, public transport, railway, and freight).  
- Existing national plans.  
- Standards and policies of European Union (EU). |
| Orlando, Florida (MetroPlan Orlando, 2017) | - ITS scoring methodology that includes 8 criteria was developed and adopted to prioritize the ITS projects related to the identified services.  
- 8 criteria chosen are as follows: Planned Priority; Existing Volume to Capacity; Stakeholder Survey Results; ITS Strategies; ITS Plan Goals and Objectives; Regional Connectivity; Safety; and Transit. |
| Orange County, California (Orange County, 2013) | - Inputs from a wide range of stakeholders in the county.  
- Existing conditions of ITS projects and programs and current state of technology.  
- Needs assessment and its results.  
- Three distinct time frames such as short-, medium- and long-term were proposed to describe deployment plan for strategy implementation. |
| Sejong, Korea (Sejong City, 2014) | - Current traffic status and issues.  
- Existing ITS services.  
- Survey from general public.  
- Existing national plans.  
- Each evaluation category was evaluated by Principle Investigators, and finally a 2-stage ITS service implementation plan was developed. |
| Seoul, Korea (Gov. of Seoul, 2008) | - Existing national ITS architecture.  
- Current traffic status and issues.  
- Overseas ITS services plans.  
- ITS services were categorized as ‘extending from existing system’ and ‘new system’, and the ‘extending’ services are implemented in the 1st stage, while the ‘new’ services are implemented in the 2nd stage. |
| Chungcheong Province, Korea (Chungcheongnamdo, 2008) | - Existing national plans.  
- Survey of the general public.  
- Survey of stakeholders.  
- Each evaluation category was evaluated by Principle Investigators, and finally a 3-stage ITS service implementation plan was developed. |
METHODOLOGY

This study suggests a systematic approach to prioritizing ITS services using the scoring criteria and evaluations. The methodology aims to ensure that the ITS services are objectively and systematically prioritized considering many aspects such as the needs survey results, the country’s plans, and the investigators’ understanding of the country’s status and issues to be resolved. Furthermore, this systematic approach is straightforward and can be readily transplanted to other countries, while there have been challenges in applying the conventional approach in other regions due to its complexity.

With these objectives in mind, five criteria are suggested and listed below. It should be noted that these five criteria were comprehensively determined based on reviews of past practices and several discussions with ITS specialists and researchers. Each ITS unit service is supposed to be scored according to these five criteria, and selected for implementation based on the total scores. The prioritization of the selected ITS unit services is also determined based on their total scores.

- **Criterion 1 (Inclusion in traffic policies and development plans of subject country)** – 20 points: If ITS services are included in transport policies and their upper-level plans of a subject country/region, a score of 20 points is given. If not, zero point will be granted.

- **Criterion 2 (Problems and needs identified by the general public)** – 20 points: Transport problems and needs are surveyed from general public through questionnaire surveys. The severity of the problems and needs is quantified in the range of zero to 20.

- **Criterion 3 (Problems and needs identified by transport experts)** – 20 points: Transport problems and needs are selected and prioritized by transport experts through questionnaire surveys. The severity of the problems and needs is quantified in the range of zero to 20.

- **Criterion 4 (Existing services currently in operation)** – 10 points: Depending on their current status of operation – operational or not – they are given a score of zero or 10 points.

- **Criterion 5 (Principal investigators’ judgment considering the traffic problems and issues of a subject country/region)** – 30 points: Depending on the urgency and importance of the introduction of systems in close collaboration between the principal investigators and the stakeholders of a subject country/region, 10, 20 or 30 points will be given.

The fifth criterion is evaluated by the principal investigators (i.e., the authors of this study) in close collaboration and discussion with local stakeholders including scholars, public and police officers. If the stakeholders find specific ITS unit services that are expected to resolve traffic problems and issues of specific regions, then the specific services are scored based on the evaluations of principal investigators and the stakeholders. This is a qualitative approach among these proposed approaches, but this should be considered to reflect the decision-making process of stakeholders. Finally, these five criteria are evaluated and the ITS unit services can be selected and prioritized based on the total scores.

In addition, this ITS services prioritization is implemented in a hierarchical manner, based on the regional characteristics such as population, density, number of vehicles, and the following traffic problems and social issues. This study focuses on developing countries which frequently show different social and traffic conditions by regions. For example, many developing countries are composed of a mega capital having high density in a small area and the other regions having low density in a large area. Hence, national ITS projects should embrace all administrative regions and their various characteristics and should not be planned only for certain areas, this study proposes to apply the ITS services prioritization methodology by regional separations.

### III. CASE STUDY

This study applied this methodology using a case study in Mongolia. To this end, a preliminary analysis was conducted to identify the regional characteristics of Mongolia. ITS services were determined based on the understanding of Mongolia; and the ITS services were finally selected and prioritized based on the methodology proposed in this study. For the preliminary analysis of this case study, the first section titled ‘Demographics and vehicle statistics’ describes the population and vehicle...
A. Demographics and vehicle statistics

The principal investigators need to understand the status (e.g. social and traffic issues) of the country in advance of selecting ITS services. Mongolia, the case study area of this study, is located in the southern part of the plateau in Central Asia, and the total area of the inland country is 1,567,000km², making it the world’s 19th-largest country in terms of the area of territory (KOTRA, 2017). Mongolia is divided into 21 administrative districts called Aimag. These Aimags are subdivided into 315 Soms. Noting that Aimag and Som can be respectively compared to ‘State’ and ‘County/City’ by international standard. Ulaanbaatar (UB), the capital, is a separate municipal district with equivalent administrative status to an Aimag. As of 2011, as shown in Figure 1, Mongolia had a population of 2,811,666. By 2016, it had grown to 3,119,935. In the past five years, the population has increased by about 308,000 people. The average annual population growth rate during 2011-2016 was about 2.1 per cent. Over 45 per cent of the total population (1,440,447 persons as of 2016) is concentrated in its capital. UB and the population within the capital has been on the rise (MSIS, 2017). The remaining 21 Aimag (equivalent to provinces) show a very low average population density of 2 persons/km², and dispersed housing patterns. This kind of dense population in urban areas is clearly witnessed in the number of registered vehicles. Over 60 per cent of the total number of registered vehicles (766,019 vehicles as of 2016) are concentrated in UB, causing serious transport problems such as severe traffic congestion, a lack of parking spaces, and air pollution (UB was ranked the second worst city in the world for air pollution) (MSIS, 2017).

Figure 1. Population and vehicles statistics in Mongolia

Approximately 45,000 traffic accidents occur in Mongolia each year, resulting in approximately 5,000 deaths (Mongolia National Police, 2016). Figure 2 shows the statistics on the accidents in Mongolia. Comparing the number of traffic deaths per 100,000 population with the average number of traffic deaths in Organisation for Economic Cooperation and Development (OECD) countries (OECD, 2017), Mongolia loses about 30 persons, 13 times higher than the figure for Norway (2.3 persons). In addition, of these 30 deaths (per 100,000 population), 21.1 deaths occur in the 21 Aimags other than UB, indicating the higher severity of traffic accidents in peripheral areas compared to the large city.
An excessive population concentration in urban areas is often observed in developing countries, and social problems caused by this high density such as those associated with traffic congestion and traffic safety have become more severe in recent years. If such traffic problems are not addressed, the overall social development of developing countries will be undermined. Therefore, the ITS master plan and the selection of ITS services should be done with understanding of the country status and their needs in the areas of mobility, safety, and the environment.

B. Needs analysis by regional separation

There are clear differences in the regional characteristics of the large cities and provincial cities in Mongolia due to the concentration of the population in cities. 40 per cent of the total population of Mongolia live in less than 1 per cent of its total areas, indicating that the situations of UB and the other areas (21 AimagS) are totally different and should be separately considered in the national ITS master plan. The differences between UB and the AimagS were clearly revealed through questionnaire surveys of the general public and transport experts. It should be noted that here, “general public” refers to the residents of the subject areas, while “transport experts” includes professor, researchers, public officers, police officers, and contractors who are engaged in transport. Table 2 shows the number of samples surveyed for this study.

This survey was conducted from July to August 2017 across the nation at major transport sites including terminals and bus stops in UB and other 21 AimagS. As a survey method, ‘face-to-face (1:1) and online survey’ was applied for the general public and ‘paper-based survey using an official template document’ was used for the experts. The following table describes the number of samples (public users and experts) for this survey.

Table 2. Survey samples

<table>
<thead>
<tr>
<th>Respondents</th>
<th>Area</th>
<th>Number of Samples</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>General public</td>
<td>UB</td>
<td>300 copies * 1 city = 300 copies</td>
<td>930 copies</td>
</tr>
<tr>
<td></td>
<td>21 AimagS</td>
<td>30 copies * 21 AimagS = 630 copies</td>
<td></td>
</tr>
<tr>
<td>Experts</td>
<td>UB</td>
<td>27 copies * 1 city = 27 copies</td>
<td>69 copies</td>
</tr>
<tr>
<td></td>
<td>21 AimagS</td>
<td>2 copies * 21 AimagS = 42 copies</td>
<td></td>
</tr>
</tbody>
</table>
An expert needs survey was conducted on the demand of and preference related to ITS services by surveying Mongolian traffic officers and professionals in universities. 52 per cent of the respondents worked in areas related to transport affairs. Of these, 32 per cent of respondents had 5-10-year work experience. Respondents to the survey for the general public were 63 per cent male and 37 per cent female. In terms of age distribution, the largest group was in 20s (57 per cent) while 29 per cent in 30s. More than 40 per cent responded that they commuted by driving.

For the results, in the survey of the general public in Mongolia, those living in UB highly recognized the severity of transport problems such as lack of parking spaces, traffic congestion, and lack and inaccuracy of public transport information, while those living in the 21 Aimags surveyed in this study highly recognized problems such as a lack of parking information and parking facilities, low quality of safety, and a lack of information on public transport information and waiting areas. It is noted that in this context, public transport refers to buses. In the survey, the transport experts responded that advanced traffic operations and management were needed in UB in priority, and the safety issue was the most serious problem in Aimags, as shown in table 2. In addition, the transport experts identified the application of automated traffic enforcement systems and fare collection systems in Mongolia in priority.

There are clear differences in the characteristics of transport in densely populated areas and non-densely populated areas in Mongolia. In this regard, it is likely to be necessary to differentiate ITS services for different regions. As such, in establishing future ITS master plans, different services need to be applied to different regions in consideration of their regional characteristics.

### C. ITS unit services selection results

While the ITS service selection and prioritization methodology proposed in this study was implemented using a case study in Mongolia, a list of ITS services was initially introduced from the Korea’s ITS architecture (MOLIT, 2010). This is because Mongolia has deployed many ITS services (e.g. speed enforcement and bus information systems) based on the Korea’s ITS architecture during the past decades. Table 3 shows the entire list of ITS unit services used for the following selection and prioritization process.

<table>
<thead>
<tr>
<th>Service Domains</th>
<th>Service Groups</th>
<th>Unit Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Management</td>
<td>Traffic administration support</td>
<td>Traffic demand management support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Road maintenance support</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pollution management support</td>
</tr>
<tr>
<td></td>
<td>Basic traveller information</td>
<td>Basic traveller information</td>
</tr>
<tr>
<td></td>
<td>Automated traffic enforcement</td>
<td>Speed limit violation enforcement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traffic signal violation enforcement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bus exclusive lane violation enforcement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Overloaded vehicles enforcement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Illegal parking enforcement</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roadside speed warning</td>
</tr>
<tr>
<td></td>
<td>Cautious roadway management</td>
<td>Poor vision segment management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poor pavement segment management</td>
</tr>
<tr>
<td></td>
<td>Traffic control</td>
<td>Obstacle management</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Real-time) Traffic signal control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Traffic signal priority control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Railway crossing signal control</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Freeway traffic management</td>
</tr>
<tr>
<td>Traffic Information</td>
<td>Traffic information integration and management</td>
<td>Traffic information integration and management</td>
</tr>
<tr>
<td></td>
<td>Integrated traffic information provision</td>
<td>Integrated traffic information provision</td>
</tr>
</tbody>
</table>
### Service Domains

<table>
<thead>
<tr>
<th>Public Transport</th>
<th>Service Groups</th>
<th>Unit Services</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Transit operations</td>
<td>Bus operation management</td>
</tr>
<tr>
<td></td>
<td>Transit information</td>
<td>Bus information provision</td>
</tr>
<tr>
<td></td>
<td>Transit reservation</td>
<td>Transit reservation</td>
</tr>
<tr>
<td></td>
<td>Para-transit operations support</td>
<td>Para-transit operations support</td>
</tr>
<tr>
<td>Electronic Payment</td>
<td>Electronic payment for public transport</td>
<td>Electronic payment for public transport</td>
</tr>
<tr>
<td></td>
<td>Electronic payment for roadways</td>
<td>Electronic toll collection</td>
</tr>
<tr>
<td></td>
<td>Electronic payment for transport facilities</td>
<td>Congestion charging</td>
</tr>
<tr>
<td>Commercial Vehicle</td>
<td>Hazardous materials vehicle safety management</td>
<td>Hazardous materials vehicle safety management</td>
</tr>
<tr>
<td></td>
<td>Heavy vehicle operations support</td>
<td>Heavy vehicle route guidance</td>
</tr>
<tr>
<td>Traveller information</td>
<td>Pre-trip travel information</td>
<td>Pre-trip travel information provision</td>
</tr>
<tr>
<td></td>
<td>En route travel information</td>
<td>Driver travel information provision</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transit traveller information provision</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pedestrians and cyclists travel information provision</td>
</tr>
<tr>
<td>Newly added</td>
<td>Environment</td>
<td>Limit decrepit diesel vehicles</td>
</tr>
<tr>
<td></td>
<td>Bicycle</td>
<td>Public bicycle support</td>
</tr>
<tr>
<td></td>
<td>Parking</td>
<td>Parking information provision</td>
</tr>
</tbody>
</table>

**Note:** The shaded cells are the selected ITS unit services to be further prioritized.

These ITS unit services, which are the candidate ITS unit services to be prioritized for UB and the other regions of Mongolia, were evaluated through the five-stage evaluation process. It should be noted that the intelligent vehicle road service group was excluded from the service selection process because self-driving-based services are far beyond Mongolia’s road and traffic situation, and some of the ITS unit services given zero points in Criteria 1, 4, and 5 were preemptively excluded prior to the prioritization process because these services were assumed to be unnecessary or far beyond the Mongolia’s traffic situation. In addition, the ITS unit services having zero points from the surveys of experts and general public were also excluded. Based on that the Mongolia's transport experts and normal people believe that these services are unnecessary in the near future in Mongolia. As a result, twenty ITS unit services (shaded areas in table 3) were selected, as shown in table 3. Of the twenty ITS unit services to be further prioritized, seventeen were extracted from the Korean ITS architecture, and three additional were proposed by the principal investigators (i.e. the authors of this study) and the stakeholders in Mongolia.

### D. ITS unit services prioritization results

The score of each ITS unit service was calculated based on the criteria and scoring scheme. Threshold values are set to establish short-term, mid-term and long-term plans based on the calculated priorities. Items for which the final score is 70 or higher are set as the first priority. Items with a final score that is 40 or higher but lower than 70 are set as the second priority. Lastly, items with a final score lower than 40 are set as the third priority. For non-densely populated areas, items with a final score of 60 or higher are set as the first priority, while items with a final score of 30 or higher but lower than 60 are set as the second priority. Items with a final score lower than 30 are set as the third priority. It is noted that as none of the ITS services are in operation in the Aimag of Mongolia, the criterion for the ITS service existence (i.e. 10 points) was not considered for the Aimag. Thus, the rated evaluation points (total 90 points) were normalized to 100 points. Based on these evaluation schemes, the priorities of ITS services were differentiated in consideration of their regional characteristics, and the evaluation and prioritization were conducted as shown in table 4.

For the UB case, bus information provision, bus operation management, basic traveller information, illegal parking enforcement, real-time traffic signal control, and parking information provision services were selected to be provided in priority. Importantly, public transport and parking are the critical issues in UB, thus it turned out that the bus information and management services and the...
illegal parking enforcement and parking information services were considered as the most fundamental services in priority. For the Aimags case, speed limit violation enforcement, bus information provision, bus operation management, basic traveller information, and electronic payment for public transport services were selected to be provided in priority. While the bus services were selected as the same with the UB case, the speed limit violation enforcement service was top-ranked in Aimags. This is because traffic safety is a more important issue in Aimags, compared to the UB’s situation that traffic congestion is the most critical issue.

Table 4. Prioritized ITS services in Mongolia (Ulaanbaatar / Aimags)

<table>
<thead>
<tr>
<th>Unit Service</th>
<th>Existence in plans</th>
<th>Needs identified by general public</th>
<th>Needs identified by experts</th>
<th>Existing ITS services</th>
<th>Judgment by stakeholders</th>
<th>Total Score</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bus information provision</td>
<td>20 / 20</td>
<td>20 / 20</td>
<td>9 / 1</td>
<td>10 / -</td>
<td>30 / 30</td>
<td>89 / 79(71)</td>
<td>1 / 1</td>
</tr>
<tr>
<td>Bus operation management</td>
<td>20 / 20</td>
<td>19 / 20</td>
<td>1 / 2</td>
<td>10 / -</td>
<td>30 / 30</td>
<td>80 / 73(66)</td>
<td>1 / 1</td>
</tr>
<tr>
<td>Basic traveller information</td>
<td>20 / 20</td>
<td>14 / 8</td>
<td>4 / 4</td>
<td>10 / -</td>
<td>30 / 30</td>
<td>78 / 69(62)</td>
<td>1 / 1</td>
</tr>
<tr>
<td>Illegal parking enforcement</td>
<td>20 / 20</td>
<td>12 / 12</td>
<td>10 / 11</td>
<td>0 / -</td>
<td>30 / 10</td>
<td>72 / 59(53)</td>
<td>1 / 2</td>
</tr>
<tr>
<td>Real-time traffic signal control</td>
<td>0 / 0</td>
<td>12 / 5</td>
<td>20 / 6</td>
<td>10 / -</td>
<td>30 / 10</td>
<td>72 / 23(21)</td>
<td>1 / 3</td>
</tr>
<tr>
<td>Parking information provision</td>
<td>20 / 20</td>
<td>20 / 20</td>
<td>0 / 0</td>
<td>0 / -</td>
<td>30 / 10</td>
<td>70 / 56(50)</td>
<td>1 / 2</td>
</tr>
<tr>
<td>Speed limit violation enforcement</td>
<td>20 / 20</td>
<td>5 / 10</td>
<td>10 / 11</td>
<td>10 / -</td>
<td>20 / 30</td>
<td>65 / 79(71)</td>
<td>2 / 1</td>
</tr>
<tr>
<td>Freeway traffic management</td>
<td>0 / 0</td>
<td>14 / 8</td>
<td>20 / 6</td>
<td>0 / -</td>
<td>30 / 20</td>
<td>64 / 38(34)</td>
<td>2 / 2</td>
</tr>
<tr>
<td>Electronic payment for public transport</td>
<td>20 / 20</td>
<td>0 / 0</td>
<td>2 / 10</td>
<td>10 / -</td>
<td>30 / 30</td>
<td>62 / 67(60)</td>
<td>2 / 1</td>
</tr>
<tr>
<td>Traffic demand management support</td>
<td>20 / 20</td>
<td>14 / 8</td>
<td>4 / 5</td>
<td>0 / -</td>
<td>20 / 10</td>
<td>58 / 48(43)</td>
<td>2 / 2</td>
</tr>
<tr>
<td>Traffic information integration and management</td>
<td>0 / 0</td>
<td>12 / 5</td>
<td>3 / 0</td>
<td>10 / -</td>
<td>30 / 10</td>
<td>55 / 17(15)</td>
<td>2 / 3</td>
</tr>
<tr>
<td>Congestion charging</td>
<td>20 / 0</td>
<td>14 / 8</td>
<td>6 / 1</td>
<td>0 / -</td>
<td>10 / 10</td>
<td>50 / 21(19)</td>
<td>2 / 3</td>
</tr>
<tr>
<td>Electronic payment for parking</td>
<td>20 / 20</td>
<td>12 / 12</td>
<td>6 / 1</td>
<td>0 / -</td>
<td>10 / 10</td>
<td>48 / 48(43)</td>
<td>2 / 2</td>
</tr>
<tr>
<td>Traffic signal violation enforcement</td>
<td>0 / 0</td>
<td>5 / 6</td>
<td>10 / 11</td>
<td>10 / -</td>
<td>20 / 10</td>
<td>45 / 29(27)</td>
<td>2 / 3</td>
</tr>
<tr>
<td>Overloaded vehicles enforcement</td>
<td>0 / 0</td>
<td>6 / 13</td>
<td>10 / 11</td>
<td>0 / -</td>
<td>20 / 20</td>
<td>36 / 49(44)</td>
<td>3 / 2</td>
</tr>
<tr>
<td>Hazardous materials vehicle safety management</td>
<td>20 / 20</td>
<td>1 / 4</td>
<td>1 / 2</td>
<td>0 / -</td>
<td>10 / 10</td>
<td>32 / 40(36)</td>
<td>3 / 2</td>
</tr>
<tr>
<td>Electronic toll collection</td>
<td>0 / 0</td>
<td>6 / 4</td>
<td>6 / 1</td>
<td>0 / -</td>
<td>20 / 10</td>
<td>32 / 17(15)</td>
<td>3 / 3</td>
</tr>
<tr>
<td>Public bicycle support</td>
<td>20 / 0</td>
<td>0 / 0</td>
<td>0 / 0</td>
<td>0 / -</td>
<td>10 / 10</td>
<td>30 / 11(10)</td>
<td>3 / 3</td>
</tr>
<tr>
<td>Limit decrepit diesel vehicles</td>
<td>0 / 0</td>
<td>0 / 0</td>
<td>0 / 0</td>
<td>0 / -</td>
<td>20 / 10</td>
<td>20 / 11(10)</td>
<td>3 / 3</td>
</tr>
<tr>
<td>Roadside speed monitoring</td>
<td>0 / 0</td>
<td>5 / 6</td>
<td>3 / 20</td>
<td>0 / -</td>
<td>10 / 20</td>
<td>18 / 51(46)</td>
<td>3 / 2</td>
</tr>
</tbody>
</table>

Notes:  

a. The left and right-values indicate Ulaanbaatar and 21 Aimags, respectively  
b. The total scores of Aimags’ cases were normalized to 100 points, and the parenthesized numbers are original values.
CONCLUSION

This study proposed a methodology for selecting and prioritizing ITS services by stage, which was tested through a case study in Mongolia. The major contribution of this study is that a systematic prioritization methodology was developed based on a scoring scheme. The remarkable features of this proposed methodology include the following: five evaluation criteria were proposed to score ITS services and ultimately to prioritize the selected ITS services, and the prioritization was conducted for two separate regions, which are UB and the other regions of Mongolia.

First of all, this study proposed a systematic approach in selecting and prioritizing ITS services using the scoring criteria and evaluations. While conventional approaches to ITS services prioritization have not been articulately defined and the principal investigators’ engineering judgment is a major factor in many cases, this study aims to minimize this subjective factor and develop a reasonable and fair methodology that can also consider comprehensive aspects such as needs, country’s status and existing plans, and expert knowledge. The ultimate goal of this systematic approach is to resolve traffic issues and improve quality of life in the target country by selecting the most effective and necessary ITS services. As this proposed systematic approach is straightforward and based on criteria and an evaluation methodology, it is expected that this methodology can be readily transplanted to other developing countries having similar characteristics in terms of demographic and social problems.

Importantly, this study proposed a hierarchical approach based on population density, suggesting the development of separate national ITS master plans for a capital city (i.e. high density in a small area) and the other low-populated regions; this is significant, as these density characteristics are frequently shown in many developing countries. National ITS projects, unlike metropolitan ITS projects, should embrace all the characteristics of large cities and provincial cities, and should not be planned for certain areas. In Mongolia, approximately 40 per cent of total population is concentrated in Ulaanbaatar, while approximately 60 per cent of population lives in the other 99 per cent of Mongolian territory. This imbalance in density should be considered in the national ITS master plan in order to suggest relevant ITS services to all regions of the country and for the effective operations in the future.

Furthermore, for the successful introduction of ITS in developing countries, it is most important to understand not only the status of transport in these countries, but also their overall conditions such as environment, culture, economic structure and infrastructure. With this view in mind, the evaluation criteria include the ITS services in the Mongolian government’s existing plans and the identified problems and needs answered by the general public and transport experts in Mongolia.

However, to ensure the reliability of the proposed methodology, the evaluation criteria and the assigned points (i.e. share) need to be further discussed and verified through many practices and studies. In addition, the ITS service selection methodology should be enhanced by taking emerging ITS services, which have not yet been introduced, into account, while the ITS services were selected from an existing Korean ITS standard and architecture in this study.

In conclusion, these systematic (i.e. criteria-based evaluation) and hierarchical (i.e. regional separation) features of the proposed methodology and approach in prioritizing ITS services would also provide a great reference for the other developing countries in Asia when developing their national ITS master plan. Although there are many different countries with different demographic and infrastructure situations and the proposed methodology needs to be validated with the different situations, this knowledge dissemination about ITS services prioritization based on a case study of Mongolia will be of help for countries that have similar characteristics to Mongolia.

ACKNOWLEDGEMENT

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REFERENCES


COST EFFECTIVE EVALUATION STUDY OF INTELLIGENT PUBLIC TRANSPORTATION SYSTEM BASED ON SOCIAL INVESTIGATION

Xiaoliang Zhang *, Dongmei Liu **, Jing Wang ***

ABSTRACT

This paper studies on the cost-effective evaluation of Intelligent Public Transport Systems application in Transit Metropolis in China, which was launched by the Ministry of Transport from 2009 to the present. The study purpose is to provide guidance for future investment of intelligent public transport systems. Five parts are included. The first part is about Intelligent Public Transport Systems equipment installation status. The second part is evaluation index system. The third part is methodology and thinking. The fourth part is case analysis. The fifth part is conclusions and useful suggestions for other regions. This study is based on the social survey, to which the respondents include passengers, public transport enterprises and government administrators in cities of different scales. A case study of intelligent public transportation despatching system is conducted, and the results obtained are close to the actual results. It is feasible and widely used to social investigation to evaluate the cost-effectiveness of intelligent public system.

Keywords: cost-effectiveness evaluation, intelligent public transport systems, social investigation, transit traveller information system, intelligent despatching system

INTRODUCTION

Urban public transport is a public welfare undertaking which satisfying the basic travel needs. It is the basic support for the normal operation of urban functions (Ministry of Transport, 2011). In recent years, with the rapid development of urbanization in China, the cities are growing rapidly and the population continues to grow. The total travel volume and travel distance of urban residents have increased greatly. At the same time, urban traffic structure has changed significantly, the proportion of motorization is rising rapidly, traffic congestion in urban central area is increasingly serious, and the pressure of environmental pollution and energy consumption is increasing.

In order to solve the urban traffic congestion and the environmental pollution of China, The State Council (2012) point out that giving priority to the development of public transport is an inevitable requirement for easing traffic congestion, transforming the mode of urban traffic development, improving the quality of people’s lives and improving the basic public service level of the government. It is a strategic choice for building a resource-saving and environment-friendly society and also encouraging the development of intelligent transportation.

In order to implement public transport priority, the Ministry of Transport launched the Intelligent Urban Public Transport Demonstration Project in the pilot transit cites, which formally started the work of "transit metropolis", and the demonstration project of intelligent public transport systems is one of the important contents. During the China’s 12th plan of the five-year national development period, the two batches of all 37 transit metropolis demonstration cities had carried out the intelligent public transport systems application demonstration project. In 2016, the China’s 13th plan of the five-year national development period, "transit metropolis" was started (Ministry of Transport, 2016). In August 2017, a
list of 50 cities was announced. Now, many cities have entered the acceptance stage. And, more and more medium and small cities start their construction and application of the urban intelligent public transport system.

But these cities do not know how to allocate funds more efficiently, and how to make plan of intelligent public transport systems which include many subsystems. They want to know which system is more economic and how to prioritize system buildings. This paper tried to do these evaluation work to find the answers for them. In this paper an evaluation index system was made. A Method of social investigation was chosen for obtaining evaluation data from all parties. A case study was also done. It is believed that the conclusions and the methods of this study will provide a reference for similar countries and regions in other parts of Asia.

I. INTELLIGENT PUBLIC TRANSPORT SYSTEM

Through literature review and survey analysis of major cities in China, intelligent public transport system includes six parts, namely information sensing system, information service system, intelligent dispatching system, decision support system, signal priority system and bus lane management system (see table.1 for specific description).

Table1. Composition of urban intelligent public transport system

<table>
<thead>
<tr>
<th>Name of intelligent public transport subsystem</th>
<th>Description on subsystem functions</th>
<th>Main user</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information sensing system</td>
<td>Basic information collection, including vehicle positioning data, passenger flow data, audio and video data, etc.</td>
<td>Public transport enterprise</td>
</tr>
<tr>
<td>Data centre</td>
<td>Data access, data processing and integration, data storage and data sharing interface</td>
<td>Competent department of public transport industry/public transport enterprise</td>
</tr>
<tr>
<td>Information service system</td>
<td>Providing public transport information query, route planning and other services</td>
<td>Competent department of public transport industry/public transport enterprise</td>
</tr>
<tr>
<td>Intelligent dispatching system</td>
<td>Making enterprise vehicle dispatching plan and vehicle and shift assignment, vehicle running monitoring, statistical statement, etc.</td>
<td>Public transport enterprise</td>
</tr>
<tr>
<td>Decision support system</td>
<td>Public transport operation monitoring, industry data statistics, analysis and decision-making on operation safety, travel characteristics, driving behaviours and other aspects</td>
<td>Competent department of public transport industry</td>
</tr>
<tr>
<td>Signal priority system</td>
<td>Monitoring positions of public transport vehicles in real time and controlling intersection signals to make public transport vehicles first pass</td>
<td>Competent department of public transport industry, public transport enterprise, traffic management department</td>
</tr>
<tr>
<td>Bus lane management</td>
<td>Road occupancy snapshot equipment are installed on bus lanes to ensure exclusive road right of public transport</td>
<td>Competent department of public transport industry, public transport enterprise, traffic management department</td>
</tr>
</tbody>
</table>

By the end of 2015, in China mainland (contains 32 provinces) there were 76.54 billion public transport passengers and 0.56 million bus vehicles (Ministry of Transport, 2016). As the current situation of intelligence public transportation system is concerned, public transportation enterprise information is basically available, the installation of vehicle information terminal equipment is 0.44 million, most cities
have more than 65 per cent installation ratio, including 1/3 of the city installation ratio of 100 per cent, the public transport card number is 0.52 billion, and ratio of use public transport card is 44.8 per cent. 37 transit metropolises have established bus dispatching system. In some cities, such as Guangzhou and Suzhou (figure 2 and figure 3), the transformation of “information operation” to “intelligent dispatching” is presented. The management of public transport is from part to whole and the comprehensive decision-making is deeper. Many cities have carried out daily monitoring, service supervision, line network optimization application, and promoted the construction and development of traffic integrated command centre and information data platform. The information monitoring and emergency management are combined. Many kinds of monitoring and emergency equipment such as vehicle video (the installation ratio is 78.4 per cent), engine temperature detection and broken glass equipment are widely used in the daily operation of public transportation.

![Figure 1. Intelligent service terminal installation rate](image)

<table>
<thead>
<tr>
<th>City</th>
<th>Installation Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daqin</td>
<td>100.00%</td>
</tr>
<tr>
<td>Wuhan</td>
<td>100.00%</td>
</tr>
<tr>
<td>Lanzhou</td>
<td>100.00%</td>
</tr>
<tr>
<td>Guiyang</td>
<td>100.00%</td>
</tr>
<tr>
<td>Liuzhou</td>
<td>100.00%</td>
</tr>
<tr>
<td><em>Zhouzhou</em></td>
<td>98.29%</td>
</tr>
<tr>
<td>Xining</td>
<td>100.00%</td>
</tr>
<tr>
<td>Hefei</td>
<td>100.00%</td>
</tr>
<tr>
<td>Ningbo</td>
<td>100.00%</td>
</tr>
<tr>
<td>Hangzhou</td>
<td>100.00%</td>
</tr>
<tr>
<td>Suzhou</td>
<td>100.00%</td>
</tr>
<tr>
<td>Shanghai</td>
<td>100.00%</td>
</tr>
<tr>
<td>Shenyang</td>
<td>100.00%</td>
</tr>
<tr>
<td>Taiyuan</td>
<td>100.00%</td>
</tr>
<tr>
<td>Yinchuan</td>
<td>96.64%</td>
</tr>
<tr>
<td>Shijiazhuang</td>
<td>96.18%</td>
</tr>
<tr>
<td>Hohhot</td>
<td>94.56%</td>
</tr>
<tr>
<td>Urumqi</td>
<td>92.51%</td>
</tr>
<tr>
<td>Kunming</td>
<td>86.43%</td>
</tr>
<tr>
<td>Nanchang</td>
<td>75.87%</td>
</tr>
<tr>
<td>Changsha</td>
<td>75.44%</td>
</tr>
<tr>
<td>Fuzhou</td>
<td>72.26%</td>
</tr>
<tr>
<td>Xining</td>
<td>70.91%</td>
</tr>
<tr>
<td>Tianjin</td>
<td>52.48%</td>
</tr>
<tr>
<td>Baoding</td>
<td>50.22%</td>
</tr>
<tr>
<td>Haibei</td>
<td>43.59%</td>
</tr>
<tr>
<td>Changchun</td>
<td>12.52%</td>
</tr>
</tbody>
</table>
In the information service, in addition to traditional websites and hotlines, the public can also get the information through the electronic station board, the mobile APP, the WeChat public number and the micro-blog, so the travel is more convenient and reliable. On the other hand, the information service content is no longer confined to the bus field, but more comprehensive and extensive, such as Shenzhen "traffic in hand" APP, and Beijing traffic APP. At the same time, the internet multi information service is gradually derived, such as Chelaile, Ruyue bus, Didi bus and other bus information services based on mobile interconnection to provide better travel experience.

In addition, the standard specification of intelligent public transport is gradually improved. In June 2014, the Ministry of transport issued the "the Guidelines on Demonstration Project of Urban Intelligent Public Transport Application Construction" (Ministry of Transport, 2014). At the same time, 11 engineering technical requirements for demonstration project of urban intelligent public transport system were compiled, such as "vehicle information terminal of city public transit dispatching". National standard such as "data communication protocol between vehicle information terminal of city public transit dispatching and control centre" was released (Ministry of Transport, 2012), and serial standard of Bus Rapid Transit Intelligent System was released. They all provide the necessary guidance for the application and construction of intelligent public transport and BRT system in each city.

II. EVALUATION INDEX

A. Literature review

We selected the following countries with mature evaluation indicators for analysis, and we have summarized the evaluation indicators of these countries, as shown in the table below.
### Table 2. National index summary

<table>
<thead>
<tr>
<th>Index</th>
<th>USA</th>
<th>UK</th>
<th>Canada</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Service level</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Energy and environment</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Productivity</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Mobility</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
<td>▲</td>
</tr>
<tr>
<td>Create ITS market environment</td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Innovative infrastructure financing methods</td>
<td></td>
<td></td>
<td>▲</td>
<td></td>
</tr>
<tr>
<td>Integration</td>
<td>▲</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Improving the fairness and equilibrium traffic flow</td>
<td></td>
<td></td>
<td>▲</td>
<td></td>
</tr>
</tbody>
</table>


In China, “10th-5Y” national science and technology “Research on Intelligent Transportation Cost Benefit Evaluation Method and Database Establishment” (WANG Xiaojing, 2004), concludes knowledge database, safety, mobility, efficiency, productivity, energy and environment, customer satisfaction, etc. and evaluates “Beijing bus hub operation scheduling management and passenger information service system demonstration project construction “and so on Tongji University (YANG Xiaoguang, 2005)

We have developed detailed indicators for six subsystems of the intelligent public transport system such as information sensing system, information service system, intelligent dispatching system, intelligent dispatching system, decision support system, signal priority system, bus lane management system. They are in the following B to G part. Each system has its evaluation index.

### B. Information sensing system

Information sensing system is the basis for construction and application of intelligent public transport system. It is the important precondition for determining the overall system intelligence. The system consists of most sensors. Therefore, the evaluation of this system mainly focuses on the following aspects:

- **Main work performance**: positioning accuracy, communication functions, basic information, image information, video information.
- **Electric performance**: withstand voltage adaptability, withstand power polarity reverse connection, withstand power source overvoltage, power-off protection performance, low-voltage protection performance.
• Electromagnetic compatibility: electrostatic discharge interference rejection, instantaneous disturbance rejection, vehicle ignition interference resistance

• Environmental adaptability: The vehicle-mounted intelligent service terminal is suitable for an open application environment therefore it should possess the following environmental suitability: climatic environment adaptability, mechanical environmental adaptability, protective properties, and disaster recovery unit.

C. Information Service System

• Performance requirements: The system update cycle should not exceed 60 seconds (from the one data starts computation to the one data completes computation). Every computation speed should be <5 seconds. The time from the one data computation completes to the one data is pushed to the terminal and displays on the terminal should be <3 seconds.

• Demands on stability and robustness: Meeting the system to run for 18 hrs. Minimally everyday (stop working from 11 p.m. to 5 a.m.). Annual fault rate: <98.8 per cent

• Information accuracy requirements: The arrival station number forecast error should not be more than 1 station. Station arrival time estimate accuracy: >78 per cent. Accuracy for degree of congestion of passengers in bus: >75 per cent

• Interface requirements: The interface is simple, generous, understandable, readable, and has good user experience. The service classification is clear, and the service navigation is quick and convenient.

D. Intelligent Dispatching System

The costs of industry management department include industry policy and fiscal subsidies, and the public costs are the public transport cost. The benefits of intelligent public transport dispatching system can be analyzed in aspects of public transport companies, passengers and industry management department as follows:

• Public transport companies: operational efficiency, vehicle operating costs, energy consumption data etc.

• Passengers: time savings and satisfaction are the main benefits;

• Industry management department: dynamic regulation, improvement in social benefits, etc.

Through the above analysis, the cost-benefit analysis indicators of intelligent dispatching system are created as shown in table3.
Table 3. Cost-benefit analysis indicators of intelligent dispatching system

<table>
<thead>
<tr>
<th>Interested parties</th>
<th>Costs</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Construction costs:</td>
<td>Management cost savings</td>
</tr>
<tr>
<td></td>
<td>‣ Initial expenses of the project</td>
<td>‣ Transport costs reduced by per cent</td>
</tr>
<tr>
<td></td>
<td>‣ Project implementation, construction and installation costs</td>
<td>‣ Operation and maintenance costs reduced</td>
</tr>
<tr>
<td></td>
<td>‣ Other expenses of the project</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Operation and maintenance costs:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Update and maintenance of equipment and system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Direct</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Indirect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time investment of enterprises in development stage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Technology accumulation of enterprise development</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Direct</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Indirect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Time</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Direct</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Indirect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Psychological feelings</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Security risk</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Direct</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Currency support</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‣ Indirect</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Policy support</td>
<td></td>
</tr>
</tbody>
</table>

**E. Decision support system**

Decision support is mainly statistics and analysis data and provides initial support for the transit network adjustment. In recent years, with the construction and promotion of transit-oriented cities of the Ministry of Transport, some cities such as Beijing, Shanghai, Guangzhou, Shenzhen, Suzhou and Foshan have gradually built the transport decision support systems, which are being optimized in the aspects of initial basic business management, daily operation monitoring, transit network optimization, service level evaluation, and data mining and analysis. Different regions have different construction and development levels, and different problems in construction and applications, such as incomplete data collection and inadequate support for decision support. There is also experience such as accurate grasp of the needs of city level decision support and gradual construction promotion, which can provide practical experience and reference value for the construction of decision support systems in other cities.

In the context of the internet, decision support is not only the work of government departments. More and more internet companies and research institutions rely on advanced technology and massive resources, mine big data value through multilateral open sharing platform, and provide richer data analysis results and decision support.

Public transport industry decision support can really do in the internet context such as analyse user group travel behaviours based on massive traffic data, internet and mobile network user data, mine traffic information valuable for industry management departments, play an auxiliary role in decision support, and provide services to government departments.
F. Signal priority system

The effect of implementation of the transit signal priority system is represented mainly by the improvement of the bus operation efficiency. The following indexes can serve as references for the assessment of the specific implementation effect.

- **Number of stoppages:** The number of stoppages is a very important index for assessing the signal control effect. As a matter of fact, the number of stoppages of the vehicles travelling on a smooth and well-controlled road is small; whereas on a crowded and badly-controlled road, the number becomes bigger. The increase in the number of stoppages indirectly reflects the increase in delay. With the signal priority system, the lower the number of stoppages at an intersection exist, the better the optimized effect is.

- **Per Capita Delay:** The per capita delay at an intersection reflects the average waiting time of bus passengers. The purpose of public transportation is the movement of people. Measuring the benefit of the signal priority system based on per capita delay has certain scientific. After transit signal priority is implemented, the per capita delay at an intersection should be reduced by 10~20 per cent.

- **Interval running speed:** The interval running speed is an important index to reflect the operation efficiency of buses. The interval running speed of the route buses to which transit signal priority is given can be increased by 10~15 per cent.

G. Bus lane management system

For cities with bus lane management system, main attentions should be paid to the following aspects in system evaluation and appraisal after construction:

- **Scale of bus snapshot equipment:** Scale of bus snapshot equipment should be considered centrally on the basis of bus lane mileage and bus line mileage. For example, Beijing has 394 km bus lane, the on-board snapshot equipment scale is of 1410 sets. Chengdu has 387 km bus lane, the on-board snapshot equipment scale is of 1115 sets. The layout scale of monitoring equipment in these two places can be well approximated to seamless monitoring of bus lanes in order to guarantee the right of bus driving.

- **Driving speed of buses on bus lane:** Driving speeds of buses on bus lane can improve clearly due to the system construction. For example, in Beijing urban area, Tong Zhou bus corridor, bus driving speed improves obviously, and travel time by bus becomes clearly shorter. In Chengdu, after construction of the system, buses can move faster by 9 per cent.

- **Number of violation according to bus snapshot and penalty:** Evaluation on effect of bus lane can be reflected by number of violation according to snapshot after construction of bus lane and by penalty. For example, number of violation by snapshot in Beijing in 2014 stood at about 30,000.

III. METHODOLOGY AND THINKING

In the face of such a complex smart bus system, the cost-benefit evaluation method is mainly based on the multi-index survey (see figure 3). Based on the above research, we know that the corresponding evaluation indexes of so many systems are very detailed and complex, so the entire survey needs to be designed. We decompose the cost-benefit survey of the whole intelligent public transportation system into several small questionnaires for the survey, and at the same time, we respectively face different objects. This makes the respondents easy to accept, and at the same time, filling in information more effective.
To design a questionnaire, the questions for different objects also need to be developed, and the indicators cannot be used to ask, sometimes the respondents cannot understand. Therefore, we combined fuzzy evaluation methods, for example, we divided users' feelings into three levels to make inquiries, such as good, medium-good, very good, they are easier to understand. There are many such transformations involved in the entire questionnaire, which require a large number of experiments and summaries.

Different types of cities of different sizes are considered in different objects, for example, big city, medium city and small city. Different objects of system use are considered, such as government workers, enterprise operators, social public, etc. The enterprise users also include the public transportation enterprise users and the internet information service enterprise users, such as Baidu, Gaode, Chelaile and so on.

Taking the survey of enterprises as an example, the questionnaires design includes: i) the cost and benefit of the enterprise's investment in bus information service; ii) the investment cost of the enterprise to the scheduling system and; iii) the use of the enterprise employee to the scheduling system including the friendly interface, improving work efficiency, the vehicle fuel consumption before and after the application of the scheduling system and the change of the overall vehicle running time.

Taking the survey for the government sector as an example, the questionnaires design includes: i) the cost and benefit brought by the government to the bus information service; ii) the government's input cost and staff use of the bus decision support system include the friendly interface situation, the use effect, and the relevant business efficiency improvement before and after the system, such as whether the financial subsidies work balance financial funds and; iii) The changes of road operation before and after the use of intelligent bus system.
IV. QUESTIONNAIRE AND CASE STUDY

A. Questionnaire

Questionnaire design should follow several important principles:

(1) Necessary background description: It can not only make the respondents willing to participate in the survey organized by the surveyors, but also improve the effectiveness of the questionnaire.

(2) The questionnaire should be as colloquial as possible so that people of all levels of education can understand it. For example, "how many minutes did it take you to wait for the bus during your recent trip?"

(3) The questionnaire is logical: For example, it investigates the public's evaluation of intelligent bus, and the design questions are set with corresponding options according to "whether take bus", "To take which bus", and "How long to wait for bus".

(4) In the survey, select questions should be set as much as possible, and the amount of questions should not be too large, otherwise users will lose patience and may give up answering questions, or they may answer questions in time, which cannot reflect the real situation. In order to avoid too large amount of questions in this research, so that the required information can be fully displayed in the same topic without making users feel the word redundancy and aversion of the topic.

Take the public transportation information service evaluation survey as an example:

Table 4. Sample form of public information service system evaluation questionnaire

<table>
<thead>
<tr>
<th>Question</th>
<th>Satisfied</th>
<th>General</th>
<th>Not satisfied</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Q1] The overall impression</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>[Q2] The convenience of the route</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>[Q3] Accuracy of information services</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

[Q4] How many minutes did it take you to wait the bus? [Single choice questions] [Compulsory questions]

○ 5-10min ○ 11-15min ○ 16-20min ○ >20min

In order to carry out the research, we have carefully designed the questionnaire. And the received questionnaires including oriented public (3022 copies), public transport enterprises (22 cities) and industry management (13 cities). The following cities are included: Beijing, Jinan, Zhengzhou, Wuhan, Changsha, Chongqing, Xian, Suzhou, Liuzhou, Guiyang, Xining, Yinchuan, Chengdu, Nanjing, Qinzhou, Xinggan, Enshi, Huanggang, Hezhou, etc.

And we also interview Chelaile, Baidu and Gaode companies, which have comprehensive transport big data open platform.
### Table 5. Questionnaires analysis summary

<table>
<thead>
<tr>
<th>System</th>
<th>Questionnaire</th>
<th>Quantitative calculation</th>
<th>Literature reference</th>
<th>The analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit Fixed-Route Operations</td>
<td>√</td>
<td>√</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Transit Safety and Security Management</td>
<td>√</td>
<td>-</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Transit Traveller Information</td>
<td>√</td>
<td>√</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Transit Decision Support Systems</td>
<td>√</td>
<td>√</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Bus Lane Management (BLM)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transit Signal Priority (TSP)</td>
<td>-</td>
<td>-</td>
<td>√</td>
<td>√</td>
</tr>
<tr>
<td>Card Payment Systems</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Passenger Flow Collection System</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Customized Bus Support System</td>
<td>√</td>
<td>-</td>
<td>-</td>
<td>√</td>
</tr>
<tr>
<td>Tourism bus support system</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Multi-modal Cooperation Management</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PT Open Big data and application systems</td>
<td>√</td>
<td>-</td>
<td>-</td>
<td>√</td>
</tr>
</tbody>
</table>

### B. Case study

Take Bus dispatching system for example. This system reverts the relevant information to the dispatching centre by detecting the system information, information of bus routes transit operation dispatching and hub monitoring information. Afterwards, the relevant base information management and operation monitoring & statistical analysis module will generate the relevant dispatching scheme, which will be transferred to the implementation terminal by relevant devices and communication technology; afterwards, dispatcher will adjust and manage the corresponding vehicle plan, vehicle schedule and dispatching need, release dispatching instructions, and finally complete the dispatching flow.

The direct users of the system are mainly bus enterprise users, benefit users for the public, and supervise users for government workers. In the questionnaire, the user experience is classified into three feeling levels according to Good - very good, Medium - very good, and very good. From this tab, we can see the function of bus dispatching system is good - very good, and the intelligent bus scheduling system to enhance the degree of 10-30 per cent.
Table 6. The use of bus dispatching system in different cities of China

<table>
<thead>
<tr>
<th>Dispatching system</th>
<th>System</th>
<th>Big city</th>
<th>Medium city</th>
<th>Small city</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basic information management</td>
<td>Good-very good</td>
<td>Very good</td>
<td>Good-very good</td>
</tr>
<tr>
<td></td>
<td>Vehicle operation monitoring</td>
<td>Good-very good</td>
<td>Very good</td>
<td>Good-very good</td>
</tr>
<tr>
<td></td>
<td>Video surveillance</td>
<td>Good-very good</td>
<td>Medium-very good</td>
<td>Good-very good</td>
</tr>
<tr>
<td></td>
<td>Card data</td>
<td>Medium-very good</td>
<td>Medium-very good</td>
<td>Good-very good</td>
</tr>
<tr>
<td></td>
<td>Statistical analysis</td>
<td>Good-very good</td>
<td>Medium-very good</td>
<td>Bad-very good</td>
</tr>
<tr>
<td></td>
<td>Operation plan</td>
<td>Good-very good</td>
<td>Good-very good</td>
<td>Medium-very good</td>
</tr>
<tr>
<td></td>
<td>Bus scheduling</td>
<td>Good-very good</td>
<td>Good-very good</td>
<td>Medium-very good</td>
</tr>
<tr>
<td></td>
<td>Intelligent dispatching</td>
<td>Good-very good</td>
<td>Good-very good</td>
<td>Good-very good</td>
</tr>
</tbody>
</table>

And from this table 6, we can see intelligent bus dispatching system to enhance the degree: Average passenger waiting time reduced 2-5 minutes, delay time reduced below 5 minutes.

Table 7. The use of bus dispatching system in different cities of China

<table>
<thead>
<tr>
<th>Dispatching system</th>
<th>City</th>
<th>Big city</th>
<th>Medium</th>
<th>Small city</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Improve system efficiency</td>
<td>Increased capacity</td>
<td>More 10-30 per cent, some &gt; 50 per cent</td>
<td>More 10-30 per cent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vehicle turnover increased</td>
<td>10-30 per cent</td>
<td>10-50 per cent</td>
</tr>
<tr>
<td></td>
<td>Improve economic efficiency</td>
<td>Operating costs decrease</td>
<td>10-30 per cent</td>
<td>10-50 per cent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dispatcher reduction</td>
<td>30-50 per cent</td>
<td>Some &lt;10 per cent and some &gt;50 per cent</td>
</tr>
<tr>
<td></td>
<td>Improve passenger satisfaction</td>
<td>Passenger satisfaction improvement</td>
<td>More 10-30 per cent, some &gt; 50 per cent</td>
<td>Some 10-50 per cent, some &gt;50 per cent</td>
</tr>
<tr>
<td></td>
<td>Enhance environmental benefits</td>
<td>Fuel consumption Reduced</td>
<td>10-30 per cent</td>
<td>10-50 per cent, some &lt;10 per cent</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Emission reduction</td>
<td>More 10-30 per cent, some &lt;10 per cent</td>
<td>More &lt;10 per cent</td>
</tr>
<tr>
<td></td>
<td>Increased mobility</td>
<td>Accident detection and cleaning save time</td>
<td>&gt; 10 min</td>
<td>&gt; 10 min</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay time reduced</td>
<td>2-10 min</td>
<td>2-10 min</td>
</tr>
</tbody>
</table>

Note: percentage statistics refer to the percentage of people who tick the item in the survey as a percentage of the total number of people in the survey.
Table 8. Intelligent bus dispatching system – quantitative calculation

<table>
<thead>
<tr>
<th>Bus dispatching</th>
<th>Big city</th>
<th>Medium city</th>
<th>Small city</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>More than 100 million</td>
<td>30-80 million</td>
<td>5-10 million</td>
</tr>
<tr>
<td>Economic benefit</td>
<td>More than 300 million</td>
<td>80-200 million</td>
<td>9-50 million</td>
</tr>
<tr>
<td>Environmental benefit</td>
<td>fuel save</td>
<td>25-75 million</td>
<td>6-18 million</td>
</tr>
<tr>
<td></td>
<td>Emission reduction</td>
<td>20-62 million</td>
<td>6-17 million</td>
</tr>
</tbody>
</table>

It can be seen from the above analysis that the intelligent bus dispatching system, excluding environmental benefits, enable the cost-effectiveness ratio of the quantifiable part about 1:3. In addition, the hardware construction has a large impact on cost. The selection of the scheduling mode directly affects the size of the dispatcher, and the difference of the dispatching personnel in different cities is greatly different. For example, the development and application of dispatching software is very mature in big cities, and user feedback is very easy to use, while in small cities, the effect of user feedback is general. It needs to improve the sharing of road information and the application of IC card data analysis.

Similar social investigation studies on various subsystems of smart bus were done, and the following evaluation summary table is made:

Table 9. Case evaluation summary

<table>
<thead>
<tr>
<th>Intelligent Urban Public Transport Systems</th>
<th>Conclusions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Information sensing system</td>
<td>+++</td>
</tr>
<tr>
<td>Intelligent dispatching system</td>
<td></td>
</tr>
<tr>
<td>Information service system</td>
<td>+++</td>
</tr>
<tr>
<td>Decision support system</td>
<td>+ + ?</td>
</tr>
<tr>
<td>Bus lane management system</td>
<td>/</td>
</tr>
<tr>
<td>Signal priority system</td>
<td>++</td>
</tr>
<tr>
<td>Public Transport big data open and application system</td>
<td>+++</td>
</tr>
</tbody>
</table>

+ = positive ; ? = unproven ; / = not covered in this study

About 43 per cent in the survey evaluation range were fully positive. 29 per cent were generally effective and 28 per cent were not shown to be effective.

Based on the above study, we can see that the application effect of the systems such as information sensing system, intelligent dispatching system, information service system, big data open and application system are better, and can be recommended for construction. The application effect of the systems such as Transit Decision Support Systems is required but the benefits need to be observed and evaluated for a longer time.

CONCLUSION

We can draw the following conclusions:

1. According to the construction basis and the user requirements, the construction can be divided into three stages, i.e. Stage A, Stage B and Stage C. Stage A is the stage for the construction of base systems, Stage B is the stage for the construction of integrated systems, and Stage C is the stage for the construction of custom systems for different users in the support of the Internet and big data. Different users can select appropriate construction according to the actual demand and the local construction situation and with reference to the specific implementation at different stages.
2. Due to the influence of urban scale, geographical features, recognition degree of local governments and other factors, the overall public transport development level among the domestic cities is discrete, and there is significant difference in the actual needs and development maturity of intelligent public transport system. If the construction of intelligent public transport system in different areas is required and restrained by the same standards, system application may be out of line with the actual needs of industry, thus resulting in the waste of human and financial resources as well as the decrease in management and operation efficiency.

3. Therefore, it is the key for guaranteeing that urban intelligent public transport system can play its due role to take actual needs as the orientation of intelligent public transport, gradually promote information technology system construction by stages, as well as continuously explore and improve the system application results.

Finally, it is effective to use questionnaire to evaluate the application of intelligent public transportation system, and the effect can be basically consistent with people’s practical experience. Of course, the research in this paper is only a stage investigation, there are still many deficiencies, and further follow-up research is needed, in particular, another 41.7 percent of systems are not covered. The limitation of future work is how to design a more perfect questionnaire system to make the questions more scientific. Another is to increase the number of survey areas to cover the whole system.

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