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Special Issue

Urban Transport

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PREFACE

The continuing requirement for better urban transport systems and the need for a healthier environment has led to the need for increased research in this area.

Innovative systems, new approaches and original ideas need to be thoroughly tested and critically evaluated before they can be implemented in practice, which highlights the importance of the papers. Moreover, there is a growing need for integration with telecommunications systems and IT applications in order to improve safety, security and efficiency. The papers in this issue also address the need to solve important pollution problems associated with urban transport in order to achieve a healthier environment.

The variety of topics covered reflect the complex interaction of the urban transport systems with their environment and the need to establish integrated strategies. The aim is to arrive at optimal socio-economic solutions while reducing the negative environmental impacts of current transportation systems.

The Editors are grateful to the reviewers, as well as to the authors for their contributions.

The Editors
2017

EFFECT OF PASSENGERS' FLOWS ON REGULARITY OF METRO SERVICES: CASE STUDIES OF ROME LINES A AND B

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ABSTRACT

The regularity is a key performance in the operation of a metro service, because it is normally affecting a large set of secondary performances: for example, punctuality, energy efficiency, economic efficiency and vehicles availability.

Human behaviours are affecting the regularity by introducing deviations between planned and actual times in various operational phases of metro services: for example, dwelling times, acceleration/deceleration times, inversion times at terminus and headways themselves.

The variability in passengers' flows is one of the most relevant parameters affecting mainly dwelling times and finally headways themselves.

In this framework, this article is specifically presenting the results of experimental surveys on metro services operating in Rome (lines A and B).

On these lines, a systematic counting of passengers boarding and alighting in the most crowded stations, combined with simultaneous measurement of actual dwelling times and headways, has been performed.

The collected results have been analysed, cleaned by inconsistent data and statistically interrelated looking for significant trends to compare with the most consolidated theoretical models and to quantify the effects in line with the literature developments, including those by the authors themselves.

Finally, the focus is on the most relevant quantitative outputs and the mainly identified and outlined further research needs.

Keywords: behaviours, metro, punctuality, railways, reliability, transport

1 INTRODUCTION

The regularity represents a key performance in the operation of a metro service, because it is normally affecting a large set of secondary performances: for example, punctuality, energy efficiency, economic efficiency, infrastructures and vehicles availability.

Human behaviours, as largely recognized in various studies [1–4], are directly or indirectly affecting the regularity, by introducing deviations between planned and actual times in various operational phases of metro services: for example, dwelling times, acceleration/deceleration times, inversion times at terminus, headways themselves.

In the literature, it is also recognized [5, 6] that the variability in passengers' flows is one of the most relevant parameters affecting mainly dwelling times and finally headways themselves.

Therefore, an ongoing research activity at the Department of Civil, Building and Environmental Engineering of Sapienza University of Rome is approaching with combined experimental and theoretical methods the problem to clarify the concerned dependence and quantify it according to various operational contexts.

In this framework, this article reports the results of field observations, carried out in some stations on lines A and B of the Rome metro. The purpose of these surveys was to detect some key operational aspects: the number of passengers alighting, boarding the trains and actual times of train arrival and closing the doors.

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2 METHODOLOGY OF SURVEYS

The survey team includes three people in ten stations, equally distributed between lines A and B of the Roman metro network (Table 1).

All the selected stations represent interchange nodes: Anagnina, Termini, Cornelia, Ponte Mammolo, Tiburtina, Piramide and Laurentina with bus network; Valle Aurelia with an urban railway; Tiburtina, Termini and Piramide with both regional and long distance railways; moreover, Termini is the interchange station between lines A and B of metro network (Fig. 1).

The surveys took place in several weekdays during the 2 h peak period (8:00–10:00) in June–July 2016.

Table 1: Stations where surveys took place.

Line A	*Line B*
Anagnina	Ponte Mammolo
San Giovanni	Tiburtina
Termini	Termini
Valle Aurelia	Piramide
Cornelia	Laurentina

Figure 1: Scheme of A and B metro lines and investigated stations.

Before proceeding with the survey observations, inspection in various stations allows to detect their characteristics in terms of number and location of entries/exits, the presence of elevators, escalators, as well as the actual movements of the passengers, who sometimes do not respect the specializations of the platforms access.

During the surveys, the acquired data were:

- time of train arrival;
- time of door opening;
- number of people getting off the train;
- number of people getting on the train.

Normally, during the surveys, two observers stood at the entrance and the exit of the platform, and the third one noted the intervals between train arrivals and doors opening and supported the observer standing in the most crowded area.

For stations with more than two accesses and affected by major passenger flows, the missing counting was surrogated by interpolation.

It was the case of Termini station on line A, where the main problem is passengers' flows mix in areas between the two platforms (Fig. 2).

The observations show that, in the investigated period, incoming passenger flows remain almost constant for about 30 min, which allows calculating rather stable average flow rates of incoming passengers.

The calculation is based on the following procedure:

a) During the 5 min before each 30 min period (7:55; 8:25; 8:55; 9:25), the observers, placed in the hallway leading to the platforms (direction of Battistini and Anagnina), count all the persons on the way to the access.
b) On the first day, observers count the passengers to Anagnina only.
c) On the following days, the calculation of passengers to Battistini is by subtracting the flows to Anagnina of the previous day from the total incoming flow.

The estimation for Termini line B station is based on a similar process, with five passengers accessing the platforms in one direction (Fig. 3).

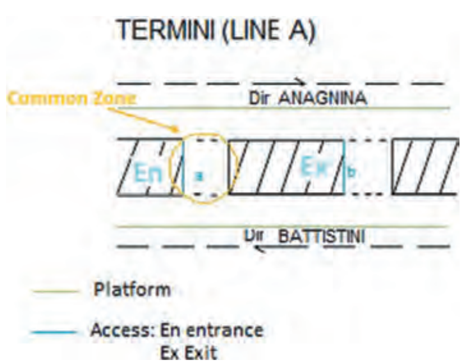

Figure 2: Termini Line A. Layout of entrance and exit to/from the platforms.

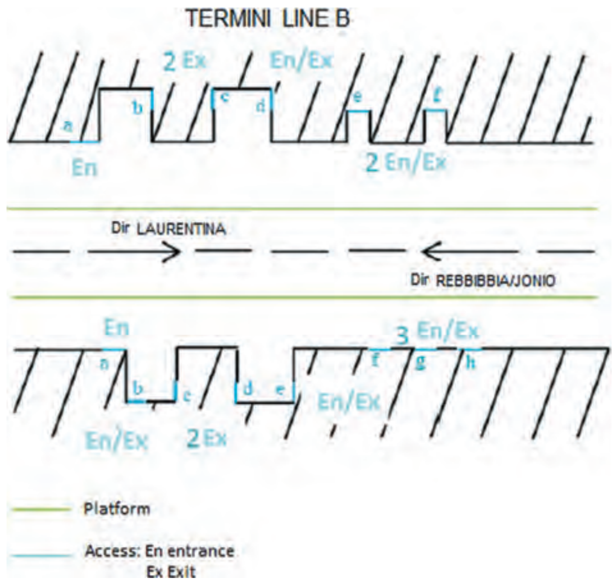

Figure 3: Termini Line B. Layout of entrance and exit to/from the platforms.

3 COLLECTED DATA

As an example of data collected according to the methodology mentioned earlier, the flows of incoming and outgoing passengers detected for some stations are in the following paragraphs:

Line A: San Giovanni (in the direction of Battistini) and Termini (in the direction of Anagnina)Line B: Tiburtina (in the direction of Laurentina) and Piramide (in the direction of Jonio/Rebibbia)

3.1 Passengers' flows on Line A: San Giovanni

In San Giovanni (in the direction of Battistini), high flows are especially incoming but the outgoing component is not negligible, especially for the time bands between 8:30 and 9:30 (Fig. 4).

3.2 Passengers' flows on line A: Termini

Termini is the main interchange node of the Roman transport network, connected with both regional and long-distance railway lines, metro line B and several buses and tram lines.

The flows reflect this situation: they always remain high and substantially balanced between incoming and outgoing (Fig. 5).

3.3 Passengers' flows on line B: Tiburtina

Tiburtina is the second railway station in Rome, interchanges with urban buses as well as with long-distance buses. The incoming flows are predominant over those outgoing and the trend shows four peaks, observable, albeit with less intensity in the pattern of outgoing flows (Fig. 6).

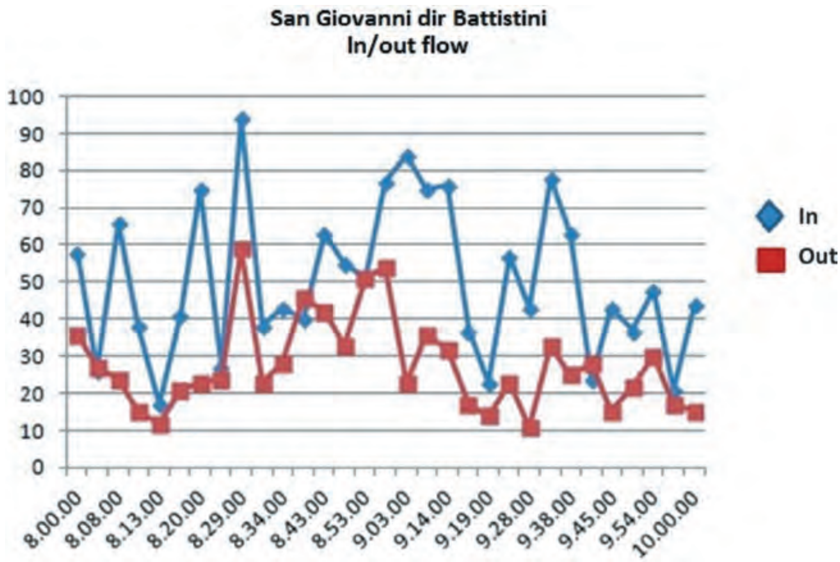

Figure 4: Line A. Incoming and outgoing flows observed in San Giovanni station (in the direction of Battistini).

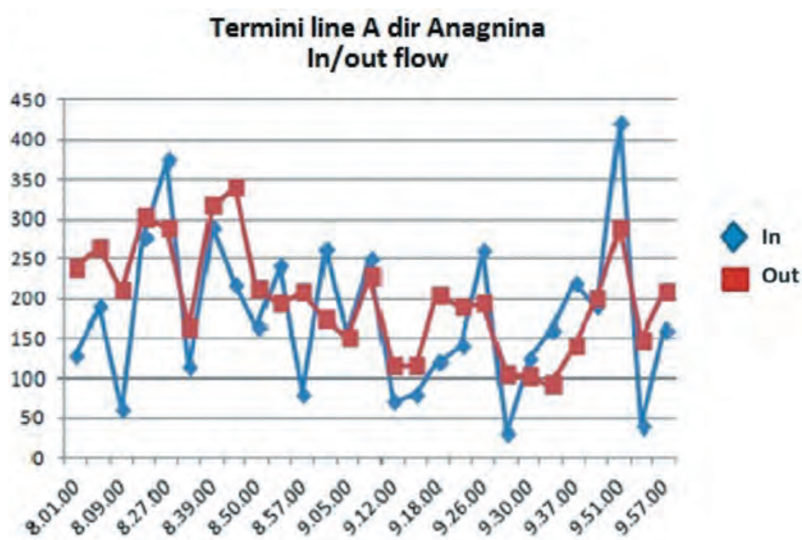

Figure 5: Line A. Incoming and outgoing flows observed in Termini station (in the direction of Anagnina).

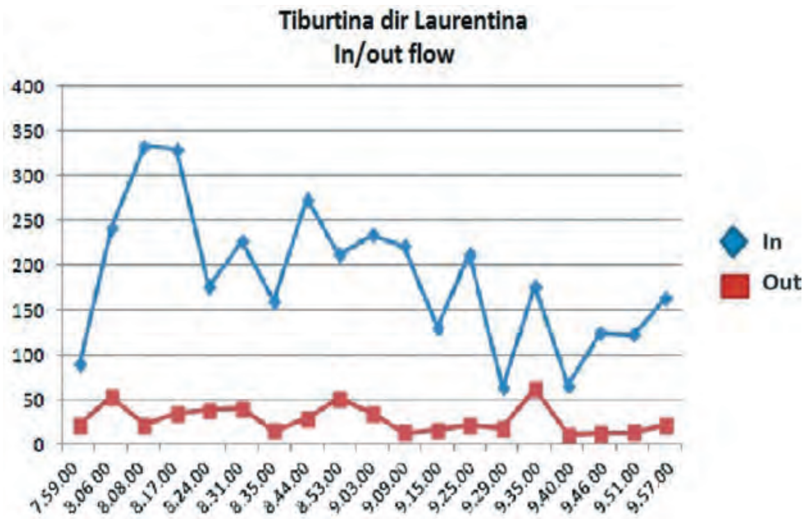

Figure 6: Line B. Incoming and outgoing flows observed in Tiburtina station (in the direction of Laurentina).

3.4 Passengers' flows on line B: Piramide

Piramide (in the direction of Jonio/Rebibbia) experiences very high incoming flows (Fig. 7), being an important interchange with the regional railways, with a self-evident peak in the time slot 8:15–8:45.

3.5 Dwell time

In addition to the passengers' flows, the survey detected the dwell time of trains in the stations too. Table 2 shows the average dwell time calculated from the measured values in each station.

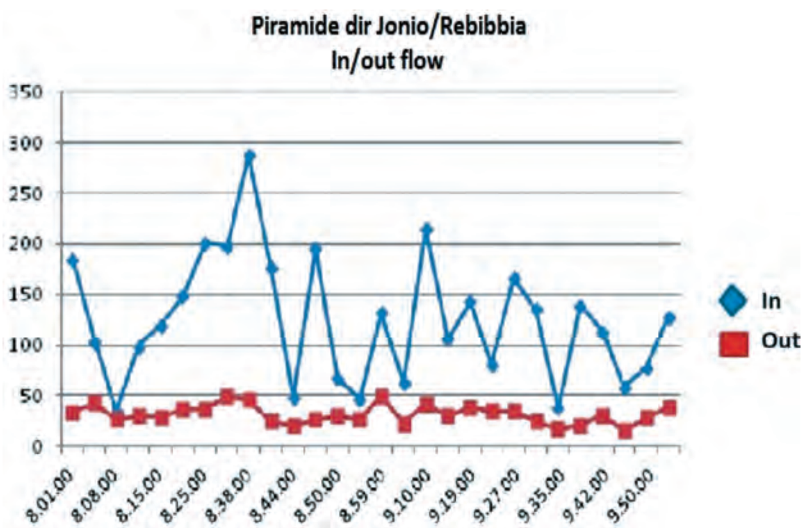

Figure 7: Line B. Incoming and outgoing flows observed in Piramide station (in the direction of Jonio/Rebibbia).

Table 2: Average values of measured dwell times.

Lines	*Stations*	*Average dwell time (s)*
A	Anagnina	18.40
	San Giovanni	14.95
	Termini	42.86
	Valle Aurelia	14.04
	Cornelia	12.98
B	Laurentina	36.02
	Piramide	25.65
	Termini	35.18
	Tiburtina	25.56
	Ponte Mammolo	15.48

4 CORRELATION BETWEEN DWELL TIMES AND FLOWS

After the data collection, the focus was on the search of a relationship between passenger's flows and dwell times.

Figure 8 represents the dwell times versus total flows, obtained by summing up all the incoming and exiting passengers for each investigated station on both lines: the area between the two red lines seems to show a possible correlation.

Nevertheless, beside it, some points indicate significantly longer dwell times, despite the rather low flows (yellow area), possibly representing irregularities due to congestion or traffic regulation measures.

Figures 9 and 10 describe the correlation between dwell times and flows, separately for lines A and B, obtained by eliminating the points included in the yellow area in Fig. 8.

Line A as a whole (Fig. 9) presents a strong correlation between dwell times and flows, with $R^2 \approx 0.80$, expressing that the linear dependence is well representing the phenomenon.

Regarding line B, the trend is more irregular and confirmed by the significantly lower value of $R^2 \approx 0.51$ (Fig. 10).

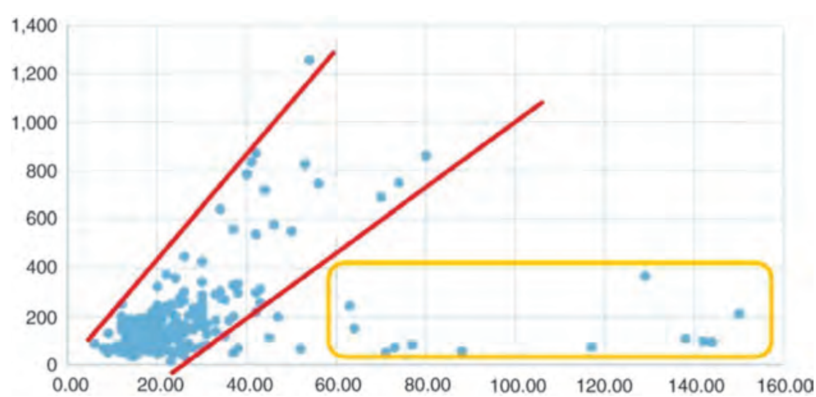

Figure 8: Dwell times (s) versus passengers' flows in all investigated stations.

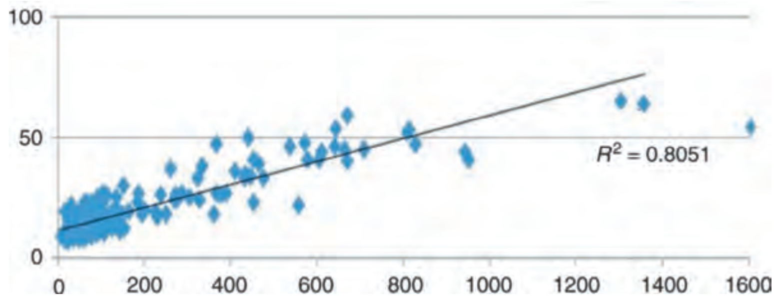

Figure 9: Dwell times (s) versus passengers' flows in line A stations.

It seems to be the result of a systematic wide dispersion of data concerning the stations in the direction Jonio/Rebibbia, while in the direction Laurentina the dispersion is lower.

The most interesting feedback is anyway in the average alighting + boarding rate, which is almost similar for both lines: about 15 passengers (incoming + outgoing) per second of dwell time.

It seems realistic when compared with an estimated maximum exchange rate per train around 48 passengers/s (2 passengers/s/door × 24 doors).

The greater dispersion in the direction of Jonio/Rebibbia might be because line B in this direction operates with branched unbalanced services towards Jonio and Rebibbia terminuses.

The consequence is that the intervals are also unbalanced and, consequently, the passengers' amount on platforms may vary significantly.

Finally, by examining the distributions for single stations, the dependence between passengers' flows and dwell times is decreasing with the entity of the flows themselves.

Exemplificative cases are:

Laurentina station on line B (Fig. 11), terminus of the line itself, which presents a substantial independence between dwell times (mainly depending on inversion manoeuvres) and flows (moderate due to the extremal location of the station and limited interchange function);

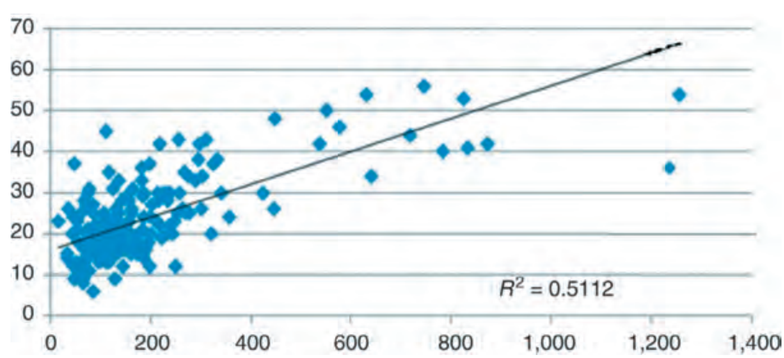

Figure 10: Dwell times (s) versus passengers' flows in line B stations.

Termini station on line A, in the direction of Anagnina (Fig. 12), key interchange station of the network, which shows a strict dependence between dwell times (the longest) and flows (the largest).

CONCLUSIONS

The first analyses on the collected data have generally confirmed the relevant dependence upon the passengers' flows of the dwell time around an almost consolidated average value of about 15 passengers/s.

However, the relationship between the two quantities is more evident in stations affected by relevant flows.

Whenever the flows decreass, the link becomes more labile until it appears almost independent upon it, due to the increasing role of operational constraints and traffic regulation issues (e.g. in Laurentina, line B terminus station).

Moreover, the greater dispersion systematically recorded in the dwell time of stations in the direction of Jonio/Rebibbia of line B, seems to depend on the presence of unbalanced branching operation.

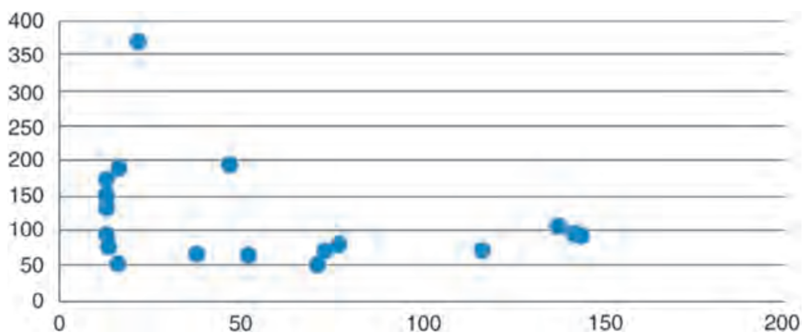

Figure 11: Dwell times (s) versus passengers' flows in Laurentina station (line B).

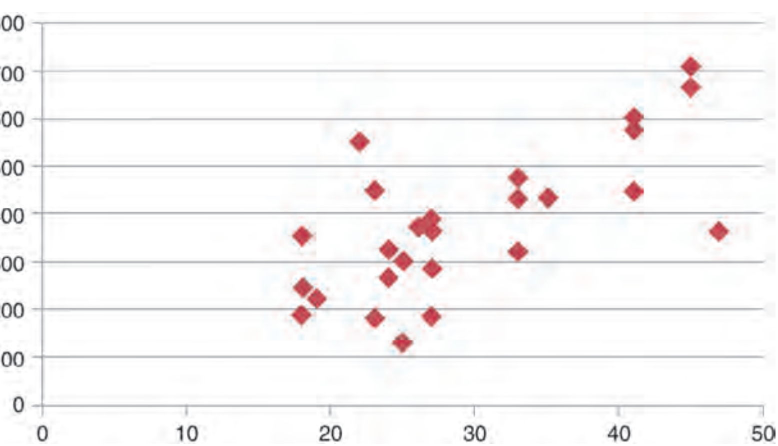

Figure 12: Dwell times (s) versus passengers' flows in Termini station (line A).

The average dwell times resulting from the survey deviate sometimes significantly from the theoretical average values considered in the scheduling process, which introduces random components and systematic disturbances in the headway, worsening the operation regularity.

Further research developments will consist both in:

- Extension of surveys in time (longer periods) and space (more stations), to investigate specifically the combination of passengers' flows and other operational factors towards the identification of a possible natural trade-off between them;
- Cross-analysis with automatically recorded operational data to investigate and identify the most relevant lines' features capable of affecting the identified dependences (e.g. unbalance between branched services revealed by the survey results for line B in the Jonio/Rebibbia direction).

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WHAT FACTORS AFFECT CROSS-MODAL SUBSTITUTION? – EVIDENCES FROM THE OSLO AREA

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ABSTRACT

The vast majority of studies on urban travel demand focus on the effect on the demand of one travel mode given a change in the characteristics of that same transport mode, for example, own-elasticities. Comparatively little is known about cross-elasticities of demand. In particular, there is a need for a better understanding of the underlying mechanisms of modal substitution, that is a better understanding of cross-modal diversion factors (DFs) defined as the proportion of people who leave mode A and switch to mode B. The purpose of this article is to investigate what factors explain variations in DFs across transport modes, submarkets and policy measures. Using a recently developed empirical travel mode choice model for the Oslo area, we simulate over 10,000 different DFs by systematically changing the underlying transport modes, submarkets and policies (size, direction and type of change). With descriptive statistics, we show how the DFs vary on a general level. Most results are immediately intuitive, for example that car drivers mostly substitute to walk for short-distance trips but that those DFs diminish rapidly with increasing distance. Interestingly, we find rather high DFs across different forms of public transportation. With successive regression analyses we show that the number of available alternatives and relative market shares significantly affect DFs.

Keywords: *cross-model substitution, diversion factors, nested logit model, sample enumeration*

1 INTRODUCTION

It is safe to say that urban passenger cross-modal substitution is not very well understood. Intermodal interaction was identified by Dodgson [1] back in 1991 as an issue in need of further research. This remains the case. It is widely accepted that it is difficult to generalize results and establish 'rules of thumb' because – as opposed to direct effects (own-elasticities) – cross-modal substitution (cross-elasticities) is very context dependent. This is because the availability and quality of travel alternatives differ greatly between study areas. A cross-elasticity towards metro, say, may be very low in city A compared to city B, not just because travellers' preferences may differ, but because the metro service may be relatively poor in city A. A related factor that adds to the variation across studies with regard to cross-elasticities is the fact that relative market shares (of altered and affected mode) directly affect the absolute value of cross-elasticities (see [2]). Surprisingly, market shares are seldom reported alongside cross-elasticities in the literature [3]. Without controlling for market shares, it is often difficult to explain variation in reported cross-elasticities.

In this article, we take a closer look at the underlying mechanisms of modal substitution by studying cross-modal diversion factors (DF). The notion of DF is straightforward. For example, say 100 persons stop travelling by car as a result of a gas price increase and that 20 of them will walk instead, 10 switch to cycling, 30 to bus, 20 to metro, 10 to train and 10 stay home and do not travel. DFs will then be 10%, 30%, 20%, 10% and 10%, respectively.

As opposed to cross-elasticities, DFs are independent of the relative market shares of the altered mode – at least as a first-order effect – and can therefore be expected to be more stable across studies [4]. Still, differences in availability and quality of alternative travel modes across studies remain a challenge when aiming for generalizable results. Also, the

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composition of trips (distribution of trip distance, trip purposes, etc.) in the empirical data is likely to affect overall results. For example, in dense cities, travel distance will be shorter on average and that will, all else being equal, cause DFs towards walking to be higher than in more spread-out cities.

Another element that can affect the comparison of evidence of cross-modal substitution is differences in the methods of data collection and modelling used. Cross-elasticities and DFs can be measured/predicted by different approaches including – among others – before–after studies [5], time series regression models [6–10] and cross-sectional choice modelling based on either stated preference [11–13] or revealed preference (RP) [14–17]. Little is known how the methodological approach may impact on study results.

The literature on DFs is limited. Some key contributions include the following. Acutt and Dodgson [18] asked 25 experts and operators for their opinion on DFs between car and train/metro/bus following fare reductions, that is, the proportion of new train/metro/bus passengers that previously used car. DFs ranged from 1% (London, car to bus) to 25% (intercity, car to train). Storchmann [19] estimated DFs from car to public transport resulting from changes in fuel taxes in Germany for various trip purposes. DFs ranged from zero percent for business, holiday and leisure trips to 100% for education trips. Adler and van Ommeren [20] studied the effects of public transport strikes during 2003–2011 in Rotterdam and found DFs from public transport to car and cycling of 27–29%. Prud'homme et al. [21] did an ex-post survey among 1,000 passengers on a Paris tramline that had been converted from bus, coinciding with a capacity reduction on a parallel road link. Their results suggest that most tram passengers were diverted from other public transport (bus 57% and subway 38%). Only 3% of the tram passengers used car previously. Murphy and Usher [22] surveyed the users of Dublin's inner-city bike sharing scheme and found that its users were diverted from walk (46%), bus (26%), car (20%) and train (9%). The Norwegian empirical evidence is very limited. Fearnley and Nossum [23] evaluated the Norwegian Ministry of Transport's 1990s urban public transport policy packages and found that 42.7% of passengers on new or improved bus services would otherwise have generated a car trip. Fearnley [24] reviewed experiences around the world with free local public transport and concluded that typically, a very low proportion of generated patronage stems from car. New passengers are more likely to generate traffic and divert from walk and cycle.

As seen from this brief literature review, the range of estimated DFs is substantial. It is likely that various factors relating to the context of the study and/or the applied method affect the empirical values.

To tackle the challenge of producing transferable results, our general approach in this article is laid out as follows: First, we control for the general context by keeping the analysis within one study area: the Greater Oslo area. Second, we base our results on one general type of model: the travel mode choice model MPM23 [25]. Third, we simulate DFs for different submarkets and different policy measures with the aim of learning how the (a) availability of modes, (b) quality of modes, (c) trip distance, (d) trip purpose, (e) type of policy, (f) size of policy change affect the simulated DFs from and towards different transport modes (car, train, bus, metro/tram, walk and cycle).

This analytical method can be referred to as *model-internal meta-analysis* as the same model is applied for a large range of policies and submarkets, and subsequent regression analysis is performed on the simulated results in a similar way as in a typical (formal) meta-analysis. Thus, the feature of 'model-internal meta-analysis' (compared to regular meta-analysis) is that the dependent variable in the regression models (DFs) is coming not from different studies found in the literature but from the same geographical context and modelling approach. Similar methodologic approaches have earlier been applied in analysing the 'package' approach to transport policy, whereby strategic or tactical models are run many times and the results are then subject to further analysis (see [26–29]).

2 THE DIVERSION FACTOR: SOME MEASURES, THEORY AND PROPERTIES

In several studies, DFs are established based on survey data. They may take the form of direct questions on how respondents would behave if their current mode became unavailable (e.g. [30]), or of transfer time (and cost) questions on intended behaviour of the form 'How much would your journey cost have to increase before you switch to another mode/don't make this trip?' (e.g. [31]). DFs are calculated as the proportion who states that they would switch to each mode (or not travel).

Another way to obtain DFs is to observe the change in demand for mode j and the proportion that diverts to mode i. Formally, this would be calculated as

$$\mathrm{DF}_{ji} = (Q_{T1\,i} - Q_{T0\,i})/(Q_{T1\,j} - Q_{T0\,j}) \tag{1}$$

where Q is demand (number of passengers); $T0$ and $T1$ are time periods or scenarios. In typical scenario analysis (e.g. two model runs), j is the transport mode that is altered in attributes, while i remains unchanged. DF_{ji} is then referred to as DF from mode j towards mode i (given a change in mode j). This is the standard procedure for deriving DFs from discrete choice models or transport models. A base scenario ($T0$) is compared with an intervention scenario ($T1$) where one (or several) attribute is (are) changed. The resulting Qs are then plotted in the above formula in order to obtain DFs.

DFs can also be calculated 'backwards' from known cross-elasticities, known own-elasticities and known market shares. We have the following relationship, which defines cross-elasticities of demand [2]:

$$\varepsilon_{ij} = |\varepsilon_{jj}| \frac{Q_j}{Q_i} \mathrm{DF}_{ji} \tag{2}$$

where ε_{ij} is the cross-elasticity of demand for mode i with respect to an attribute change of mode j; $|\varepsilon_{jj}|$ is the absolute value of mode j's own-elasticity of demand; Q_j/Q_i is the ratio of market shares or ratio of volumes; and DF_{ji} is the proportion of those who leave mode j and switch to mode i. It follows that

$$\mathrm{DF}_{ji} = \frac{\varepsilon_{ji}}{|\varepsilon_{jj}|} \frac{Q_i}{Q_j} \tag{3}$$

When inserting the definition of linear-arc-elasticities in eqn (3), it is straightforward to show that eqn (3) is mathematically equivalent with eqn (1).

Note that the sum of DFs from mode j to all other transport modes i adds up to 100% when travel mode choice is the only behaviour dimension in the modelling framework. When trip generation is included (or the choice model includes an option for 'not travelling'), the sum of DF towards a transport mode which is improved can be smaller than 100% when the improvement creates generated traffic (or a worsening leads to suppressed transport). When transport modes are substitutes (the usual case), DFs are non-negative. For complementary modes, DF can be negative. In this case, for two complementary modes, it can be that DF towards a third mode is above 100%. For example, consider a measure that yields an increase in train ridership of 100 persons. Assume that metro is – on average – a complement to train and every 10th new train user generates one additional metro trip. Assume this makes 110 fewer bus trips; then the DF from train to bus would be 110%.

DFs are 'directional', i.e. $\mathrm{DF}_{ji} \neq \mathrm{DF}_{ij}$ in general. It is worth noting that, in the literature, DFs are sometimes defined interchangeably as 'proportion of travellers that leave mode *i* and switch to mode *j*' on the one side, or as 'proportion of new travellers on mode *j* that switched from mode *i*'. There is no reason at all for these to be the same quantum: To say that 20% of new bus passengers previously used car is in fact essentially different from saying that 20% of motorists who leave the car would switch to bus. The fact that this is often treated as the same phenomenon in the literature may relate to a failure to understand Bayes's theorem and conditional probabilities.

Note that DF may also be non-symmetric for a given altered mode *j*, for example can price increase of mode *j* make a higher proportion substitute to mode *i*, than a price reduction would attract from mode *i*. This is intuitive in real life and an important question relates to which methods would allow to preserve/capture such a non-symmetry. As a point estimate, $\mathrm{DF}_{\mathrm{AB}}$ should be the same quantum whether it be 'the proportion of traffic lost to *j* which switches to *i* if *j* gets worse' or 'the proportion of *j*'s new traffic which has come from *i* if *j* gets better'. For DFs that are calculated as in eqn (1), this may not be the case when the underlying model is nonlinear in attributes. For instance, when quantities are predicted with logit models a certain non-symmetry is expected given the S-shape of the logit model. However, if changes in attributes are small (e.g. 1% and −1% changes) results will tend to be close to symmetrical.

In the introduction section, it was mentioned that DFs are independent of the relative market shares at a first-order effect. That is, eqn (1) does not involve market shares of *i* and *j*. However, it is likely that market shares represent the competitiveness of travel alternatives and are therefore likely to influence the changes in quantities in eqn (1). For instance, $(Q_{T1\,i} - Q_{T0\,i})$ is likely to be great in absolute terms when mode *i* is a highly competitive transport mode and therefore a likely substitute to mode *j*.

Furthermore, when quantities in eqn (1) are predicted on the basis of multinomial logit models we can establish a direct relationship (see the appendix for the derivation):

$$\mathrm{DF}_{ij} = P_j / (1 - P_i) \tag{4}$$

where P_j, P_i are (individual) choice probabilities for mode *j* and *i*, respectively.

Equation (4) holds true on an individual level, in which case DF_{ji} is interpreted by relative probabilities to switch from mode *j* to mode *i*. Aggregating over (heterogeneous) individuals (as done in this article by means of sample enumeration), eqn (4) does *not* necessarily hold on a market level, in which case *P* represent market shares. Note also that for nested logit models, eqn (4) applies only for modes of the same lowest level nest. The relationship between market shares and DFs is empirically investigated in the later analysis of this article.

3 METHODOLOGICAL APPROACH

Recently, Flügel et al. [25] established a travel mode choice model, referred to as MPM23, for short-distance trips within Norway's capital Oslo and the surrounding county Akershus. MPM23 is a nested logit model that calculates choice probabilities of nine alternatives that are structured into four nests: car (includes choice alternatives: car driver and car passenger), walk, cycle and PT (includes choice alternatives: train, bus, metro/tram, combinations with train and combination of bus and metro/tram). Model parameters are estimated from travel surveys, where respondents reported trip diaries of the day before the interview was conducted. Respondents do only report their actual behaviours (chosen transport mode, trip purpose, etc.), that is RP data. The model includes the usual level-of-service (LoS) attributes as well as several dummy variables that calibrate the choice probabilities for different submarkets. Trip frequency is not modelled, nor is destination choice or traffic assignment.

The estimated model is implemented in Microsoft Excel with an intuitive user interface for stylized scenario analysis. Users can specify changes in LoS variables in percent of the base values. The model predicts new market shares by sample enumerating choices of 14,947 observations (single trips). The method of sample enumeration has a long tradition (going back to at least Ben-Akiva and Atherton [32]). An attractive feature is that it preserves information at the individual level. This is important in the case of MPM23, among others because the model operates with choice sets defined at the individual level (see later).

In theory, it would be possible to differentiate the full MPM23 model and extract (individual) DFs directly by eqn (4). However, each individual in each submarket (trip purpose, geography, distance) faces different constraints and different availabilities of transport modes. There is simply not one effect on mode choice that applies to all individuals. As we are interested on results on a market (submarket) level, we must run MPM23, predict individual choice in behaviour but calculate DFs on a market (submarket) level.

For the analysis in this article, nine choice alternatives in MPM23 are merged into six travel modes as described in Table 1.

Reducing from nine to six choice alternatives eases interpretation, streamlines analysis and increases transferability of the results. A disadvantage with this procedure is that the category bus (metro/tram) might include some trips that are actually made by train and metro/tram (bus).

We use MPM23 to predict changes in ridership given policy scenarios and we calculate DFs applying eqn (1). In total, we have calculated 11,560 single DFs. Table 2 lists the variables by which the scenarios differ from each other.

The combination of the latter three categories yields 36 submarkets (2 trip distances * 3 geographies * 6 trip purposes). Three of those submarkets had less than 30 observations in the data set and were merged together resulting in 34 submarkets. Table 3 presents sample size and baseline market shares of these submarkets.

Table 1: Travel alternatives in MPM23 and in this article.

Travel modes in MPM23	**Shares going into new categorization**
Car driver	100% to car
Car passenger	100% to car
Walk	100% to walk
Cycle	100% to cycle
Train (without transfer to other PT)	100% to train
Bus (without transfer to other PT)	100% to bus
Metro/tram (without transfer to other PT)	100% to metro/tram
Combination with train	50% to train, 25% to bus, 25% to metro/tram
Combination with bus and metro (not train)	50% to bus and 50% to metro/tram

Table 2: Underlying variables in scenario simulations.

Travel mode altered	Policy variable	Size of change	Travel mode affected	Trip distance	Geography	Trip purpose
• Car • Train • Bus • Metro/ tram	• In vehicle time • Out-of-pocket costs* • Access/egress time (not car) • Waiting time (not car) • Number of interchanges (not car)	• −30% • −1% • +1% • +30%	• Car • Walk • Cycle • Train • Bus • Metro/ tram	• <5 km • >5 km	• Urban • Suburban • Urban to/from suburban	• Commuting • School • Business • Grocery • Deliver/pick up • Other leisure

* Includes fuel and road tolls cost for car and single ticket prices for PT (users with season ticket have zero costs in the current version of MPM23).

Table 3: Sample size and baseline market shares of 34 submarkets.

Index	Characteristic of submarket*	*N*	Baseline market shares (%)					
			Car	Walk	Cycle	Train	Bus	Metro/ tram
1	>5 km; urban; commuting	983	32.7	2.0	8.9	6.9	18.0	31.5
2	>5 km; urban; school	103	8.1	1.1	5.3	5.2	22.3	58.0
3	>5 km; urban; business	73	50.6	1.0	3.5	4.3	15.4	25.1
4	>5 km; urban; grocery	354	56.3	2.4	4.4	3.9	11.9	21.1
5	>5 km; urban; deliver/pick up	135	75.2	2.4	4.2	1.6	6.7	10.0
6	>5 km; urban; other leisure	607	41.3	4.5	6.2	3.4	16.6	28.2
7	>5 km; suburban; commuting	517	86.0	0.5	2.6	4.5	6.0	0.4
8	>5 km; suburban; school	48	23.5	1.5	8.1	17.3	47.4	2.1
9	>5 km; suburban; business	31	91.3	0.4	1.1	3.4	3.6	0.2
10	>5 km; suburban; grocery	456	92.1	0.8	1.7	1.6	3.9	0.1
11	>5 km; suburban; deliver/pick up	193	97.1	0.4	0.8	0.4	1.2	0.0
12	>5 km; suburban; other leisure	514	87.4	1.1	2.0	3.0	6.2	0.3
13	>5 km; u to/from s; commuting	1,423	54.0	0.3	3.6	16.2	18.4	7.5
14	>5 km; u to/from s; school	63	15.6	1.3	4.1	31.2	32.1	15.7
15	>5 km; u to/from s; business	96	67.5	0.1	1.1	9.9	15.9	5.5
16	>5 km; u to/from s; grocery	421	76.4	0.5	1.7	10.5	7.5	3.4
17	>5 km; u to/from s; deliver/pick up	236	92.1	0.5	1.2	1.9	2.6	1.7
18	>5 km; u to/from s; other leisure	771	67.8	1.2	3.0	10.2	12.6	5.3
19	<5 km; urban; commuting	839	18.3	32.9	14.0	0.3	14.0	20.5
20	<5 km; urban; school	96	5.7	27.4	9.9	0.7	24.5	31.9
21	<5 km; urban; business	83	27.6	28.9	6.2	0.3	9.1	27.8
22	<5 km; urban; grocery	1,492	33.0	50.3	5.6	0.0	4.9	6.2
23	<5 km; urban; deliver/pick up	485	49.8	40.6	4.7	0.0	2.8	2.1

(*Continued*)

Table 3: (*Continued*)

Index	Characteristic of submarket*	*N*	Baseline market shares (%)					
			Car	Walk	Cycle	Train	Bus	Metro/ tram
25	<5 km; suburban; commuting	213	60.5	25.6	8.4	0.2	5.3	0.0
26	<5 km; suburban; school	35	21.8	38.5	19.0	1.4	19.2	0.0
27	<5 km; suburban; grocery	773	70.2	24.0	3.5	0.1	2.1	0.0
28	<5 km; suburban; deliver/pick up	370	80.0	17.3	2.1	0.0	0.7	0.0
29	<5 km; suburban; other leisure	751	50.9	41.7	4.7	0.1	2.6	0.0
30	<5 km; u to/from s; commuting	139	56.9	20.7	10.2	1.1	9.3	1.8
31	<5 km; u to/from s; grocery	421	65.6	26.2	3.5	0.2	3.8	0.7
32	<5 km; u to/from s; deliver/pick up	213	79.6	16.0	2.7	0.3	1.3	0.1
33	<5 km; u to/from s; other leisure	393	45.1	44.6	5.1	0.2	4.1	0.9
34	<5 km; remaining	38	64.4	17.2	4.9	0.6	12.9	0.0

* ‘u to/from s’ means ‘urban areas to/from suburban areas’.

Overall, car has the highest market shares in the Greater Oslo area. This holds true for most submarkets. Exceptions are school trips and most short-distance (<5 km) urban trips.

Not surprisingly, the market share for walking varies considerably between short-distance and long-distance trips. Cycling has higher market shares for commuting and school trips. Train is barely used for trips under 5 km and has its highest market shares on longer suburban and ‘suburban to/from urban’ trips. Also, the market shares for bus vary greatly across submarkets; school trips are particularly often done by bus. Bus – and to an even higher degree metro/tram – has higher market shares for urban than for suburban trips. There are no short-distance metro/tram trips within suburban areas since metro/tram is not available there. The market shares for metro/tram trip departing and/or ending in suburban areas are in reality trips made by combinations of transport modes but are coded as metro/tram with the applied method.

The competitive structure in the 34 submarkets can also be described by the available choice alternatives (Table 4). Whether a travel mode is ‘available’ or not is defined by MPM23 on a trip level. Car is always available, as the model assumes that you can always be ‘car passenger’. For walk and cycle, availability is defined by the trip distance, with limits of availability of 10 and 40 km, respectively. Availability of PT is mainly defined by distance to the nearest station in a similar fashion (see [25] for details).

For submarkets with shorter trips (<5 km), train and, to a lower degree, metro/tram are seldom defined as available due to unreasonably long access/egress times to the nearest station. The availability for walk decreases rapidly for submarkets with longer trip relations.

The overall methodical approach of our analysis is briefly summarized in Fig. 1.

4 DESCRIPTIVE STATISTICS

In this section, we present some descriptive statistics from the results of the model simulations. Regression analyses are presented in Section 5.

As DFs have a close connection to cross-elasticities (see equation (2)), we have also simulated own- and cross-elasticities of demand alongside DFs. All simulated own-elasticities are negative. This is expected given that all analysed policy variables are ‘bads’, for example an

Table 4: Average distance and availability of modes (averages over trips within submarkets).

Index	Characteristic of submarket*	Average distance (km)	No. of available travel modes	Availability by mode (%)**					
				Car	Walk	Cycle	Train	Bus	Metro/ tram
1	>5 km; urban; commuting	9.0	4.9	100	73	100	30	97	90
2	>5 km; urban; school	9.1	4.8	100	71	100	17	93	95
3	>5 km; urban; business	8.6	5.0	100	82	100	27	97	89
4	>5 km; urban; grocery	8.2	4.9	100	83	100	24	97	85
5	>5 km; urban; deliver/ pick up	8.8	4.8	100	73	100	22	96	88
6	>5 km; urban; other leisure	8.4	4.8	100	80	100	20	96	86
7	>5 km; suburban; commuting	19.8	4.1	100	25	90	62	96	39
8	>5 km; suburban; school	18.5	4.2	100	38	88	65	100	33
9	>5 km; suburban; business	17.8	4.0	100	32	87	61	87	32
10	>5 km; suburban; grocery	13.0	4.2	100	54	97	53	88	26
11	>5 km; suburban; deliver/p. up	19.3	4.1	100	51	88	50	90	32
12	>5 km; suburban; other leisure	18.9	4.1	100	43	88	55	88	33
13	>5 km; u to/from s; commuting	20.9	4.6	100	21	90	72	97	79
14	>5 km; u to/from s; school	18.7	4.8	100	29	95	81	98	81
15	>5 km; u to/from s; business	21.1	4.5	100	22	91	69	95	75
16	>5 km; u to/from s; grocery	18.9	4.7	100	35	91	76	98	73
17	>5 km; u to/from s; deliver/p. up	18.6	4.5	100	36	88	61	96	68
18	>5 km; u to/from s; other leisure	18.6	4.6	100	32	92	68	96	73
19	<5 km; urban; commuting	2.8	4.4	100	100	100	10	68	58
20	<5 km; urban; school	2.8	4.4	100	100	100	8	70	60
21	<5 km; urban; business	2.5	4.3	100	100	100	13	51	64
22	<5 km; urban; grocery	1.7	3.6	100	100	100	3	30	22
23	<5 km; urban; deliver/ pick up	1.8	3.5	100	100	100	1	28	17
24	<5 km; urban; other leisure	2.0	3.8	100	100	100	5	38	34
25	<5 km; suburban; commuting	2.6	3.4	100	100	100	8	32	1
26	<5 km; suburban; school	2.6	3.5	100	100	100	6	40	3

(*Continued*)

Table 4: (*Continued*)

Index	Characteristic of submarket*	Average distance (km)	No. of available travel modes	Availability by mode (%)**					
				Car	Walk	Cycle	Train	Bus	Metro/tram
27	<5 km; suburban; grocery	2.2	3.2	100	100	100	2	21	0
28	<5 km; suburban; deliver/pick up	2.3	3.2	100	100	100	1	16	0
29	<5 km; suburban; other leisure	2.2	3.2	100	100	100	3	18	0
30	<5 km; u to/from s; commuting	3.2	4.1	100	100	100	17	70	19
31	<5 km; u to/from s; grocery	2.3	3.6	100	100	100	8	40	12
32	<5 km; u to/from s; deliver/p. up	2.6	3.5	100	100	100	7	37	6
33	<5 km; u to/from s; other leisure	2.1	3.5	100	100	100	7	31	10
34	<5 km; remaining	2.9	3.7	100	100	100	13	50	3

* 'u to/from s' = 'urban areas to/from suburban areas'.
** As defined on an individual trip level in MPM23.

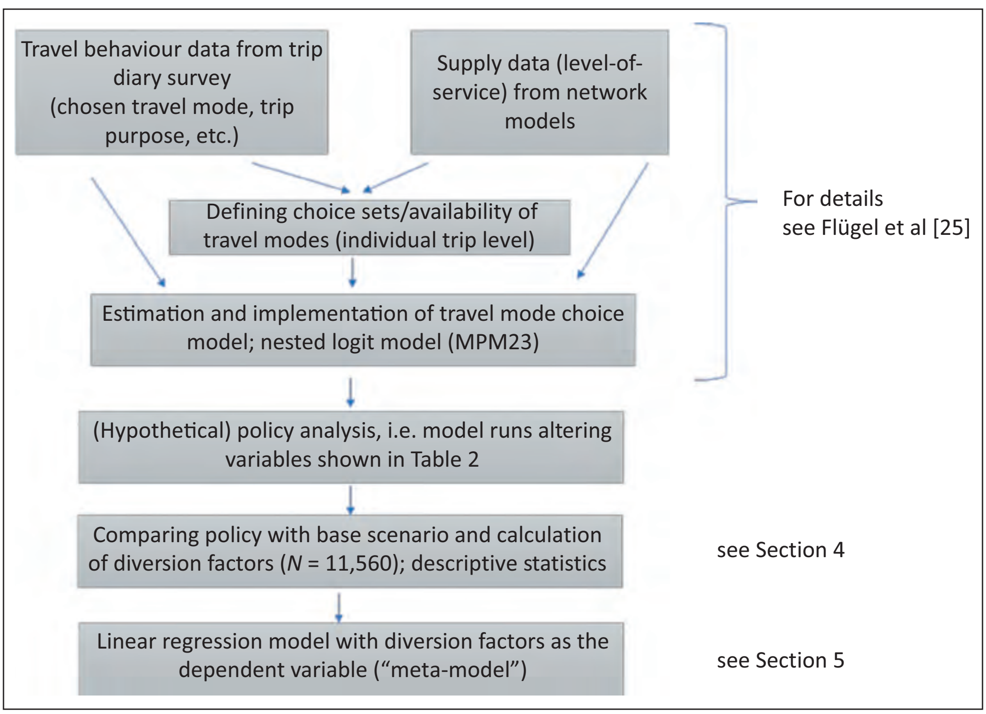


Figure 1: Overall methodological approach.

increase in LoS variable as travel cost, in-vehicle time, waiting time, access–egress times and number of interchanges for mode *j* leads to a decrease in ridership of mode *j*.

The simulated cross-elasticises are typically positive but some cross-elasticities that involve metro/tram are negative (but rather low in size). These are typically cases for suburban areas where metro/tram is only used in combination with bus or train. In these cases, metro/tram is a complement rather than a substitute to bus and train. This would be the case for commuters who take a train or bus into central Oslo and from there take metro or tram to their final destination within Oslo.

It is important to note that cross-elasticities are highly dependent on the relative market shares between the affected and altered transport modes. If the relative market share is high (the affected mode has a much higher market share than the altered mode), cross-elasticities are typically very close to zero (Fig. 2). This underlies the point made in the introduction section about cross-elasticities, which is context dependent and difficult to interpret without considering the underlying market shares.

DFs are less affected by market shares, as shown in Fig. 3. Even for high relative market shares we find a widely spread DFs. However, there appears to be a positive relationship between relative market shares and DFs, which may relate to the theoretical properties of the underlying logit models (see eqn 4). A positive correlation between market shares and DFs does generally make sense because the market share of mode *i* is likely to be proxy for the competitiveness (or 'LoS') of mode *i*.

The following figures show how DFs vary by transport mode combination and for group of submarkets (aggregates of the 34 submarkets used for simulation). Figure 4 shows average

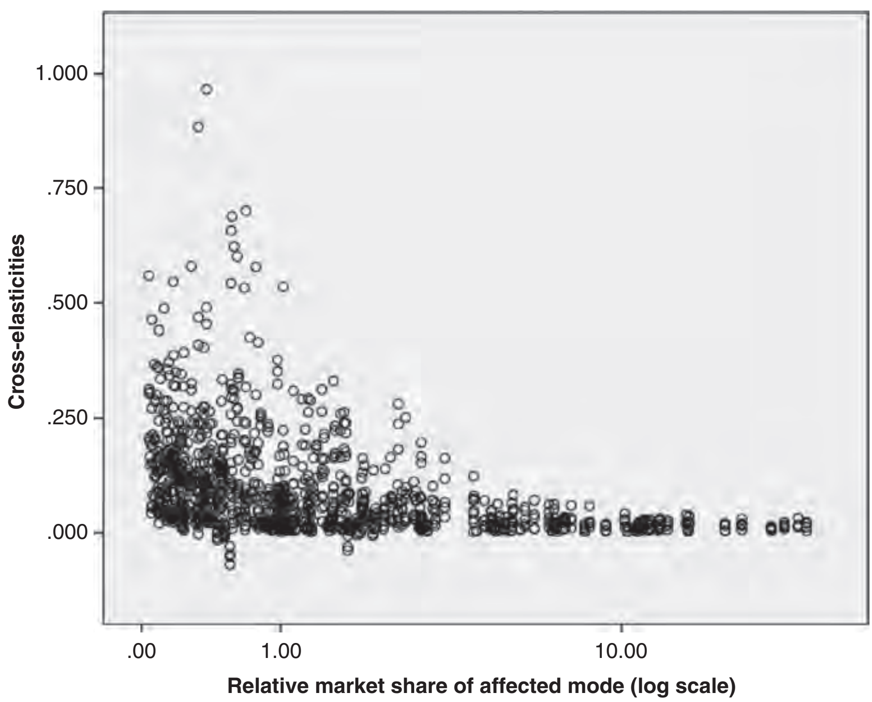


Figure 2: Simulated cross-elasticities and relative market shares.

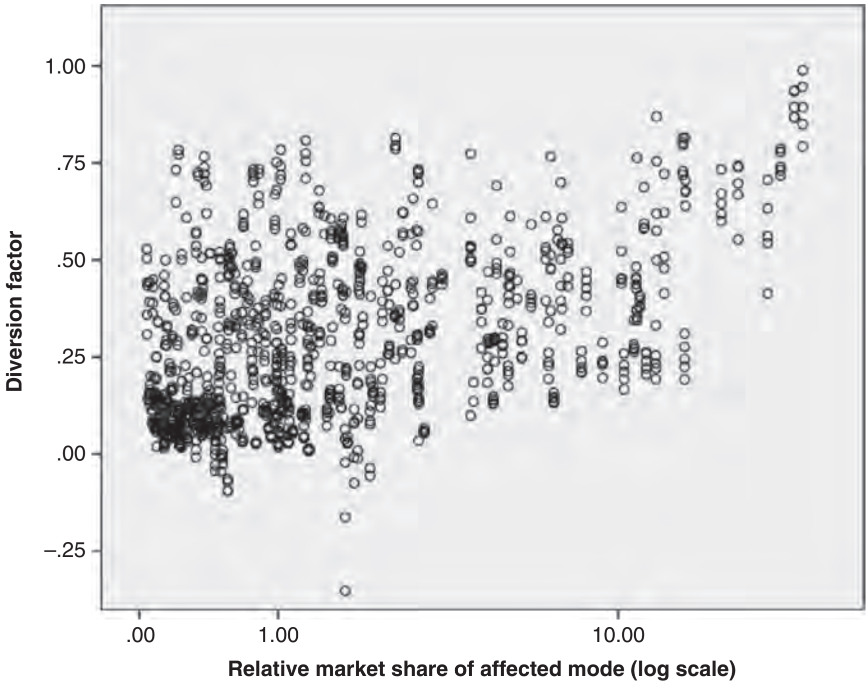
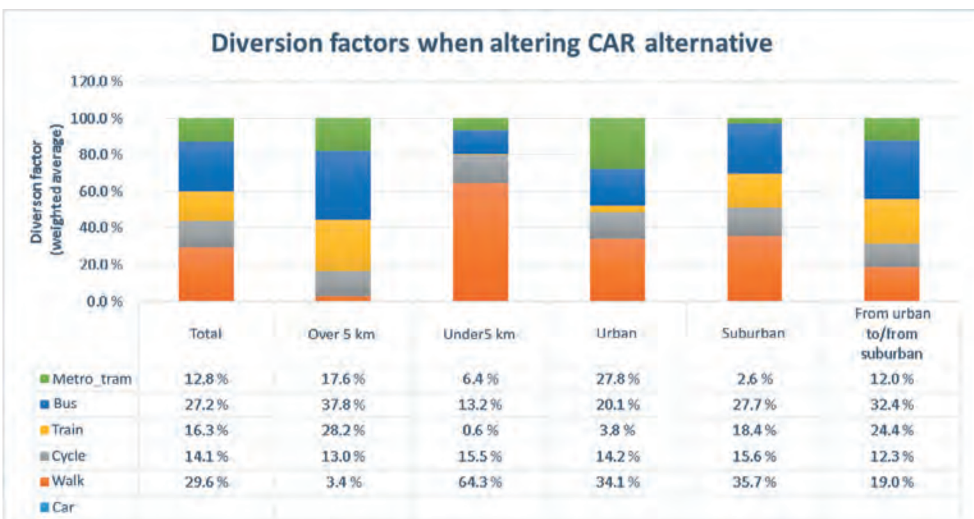


Figure 3: Simulated diversion factors and relative market shares.



	Total	Over 5 km	Under5 km	Urban	Suburban	From urban to/from suburban
Metro_tram	12.8 %	17.6 %	6.4 %	27.8 %	2.6 %	12.0 %
Bus	27.2 %	37.8 %	13.2 %	20.1 %	27.7 %	32.4 %
Train	16.3 %	28.2 %	0.6 %	3.8 %	18.4 %	24.4 %
Cycle	14.1 %	13.0 %	15.5 %	14.2 %	15.6 %	12.3 %
Walk	29.6 %	3.4 %	64.3 %	34.1 %	35.7 %	19.0 %
Car						

Figure 4: Diversion factors, total and by main categories, when car is altered.

values of DFs when the car alternative is altered. Observations are weighted by the size of each submarket and the market share of car in these submarkets.

Note that both −30%, −1%, 1% and 30% changes in attributes are included; that is potential asymmetry is not taken into account here (see later discussion).

Overall, bus and walk have the highest DFs than car travel. The DF of 27.2% for bus and 29.6% for walk can be interpreted with a hypothetical scenario that leads to 1,000 fewer (more) car trips. About 272 would come from (go to) bus, while 296 would come from (go to) walk.

DFs vary with submarkets. Walk dominates for trips under 5 km. Bus, together with train, is the best alternative to car for longer trips. For urban trips, metro/tram has a relatively high DF. This is directly related to availability (see Table 4). For suburban trips its DF is low. The opposite pattern is observed for train.

Figure 5 shows the corresponding picture when bus attributes are altered. The highest DFs are found for car on longer trips and trips within suburban areas, and for metro/tram on shorter and urban trips. For suburban travel, metro/tram and bus seem rather to be complementary, as indicated by the slightly negative DF. In total, close to 50% (33.1% + 16.2%) of bus users divert to other PT options. This finding is discussed in Section 6.

Figure 6 gives the results of simulations where train attributes are altered. Not surprisingly, the DF for walk (and cycle) is very small. Bus and car are main competitors for train as judged from the simulated DFs although a substantial diversion to metro/tram can be seen on short and urban trips.

Some interesting patterns are shown in Fig. 7, where DFs are calculated for attribute changes in metro/tram. For trips within suburban areas (where metro/tram has rather low market shares, and most of the ridership stems from trips where metro/tram is used in combination with PT modes), we find negative diversion to both bus and train. Fewer metro/tram passengers will also reduce bus and train patronage. In this market, there is therefore complementarity between metro/tram and bus and train. Apart from suburban trips, bus has high DFs when metro/tram is altered. Diversion to car is also significant in all submarkets, with the exception of short trips where diversion to walk is prominent.

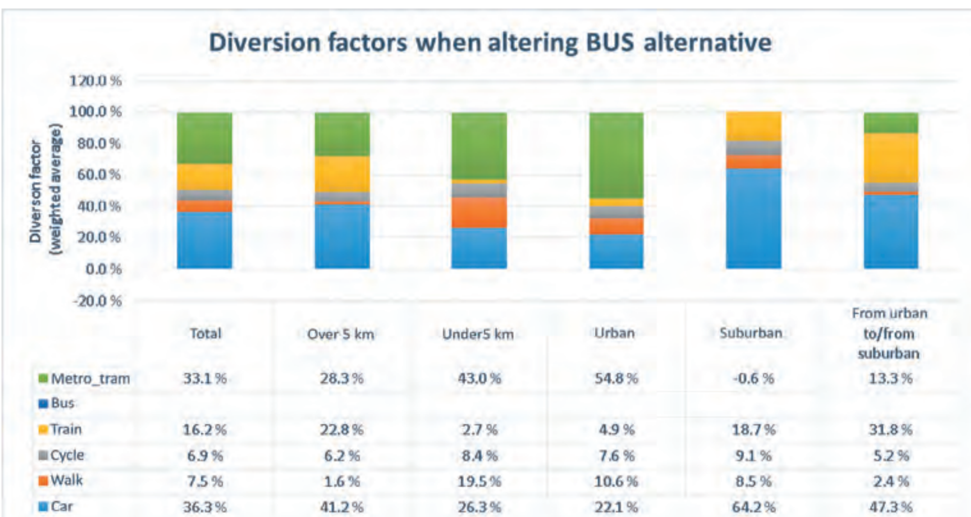


Figure 5: Diversion factors, total and by main categories, when bus is altered.

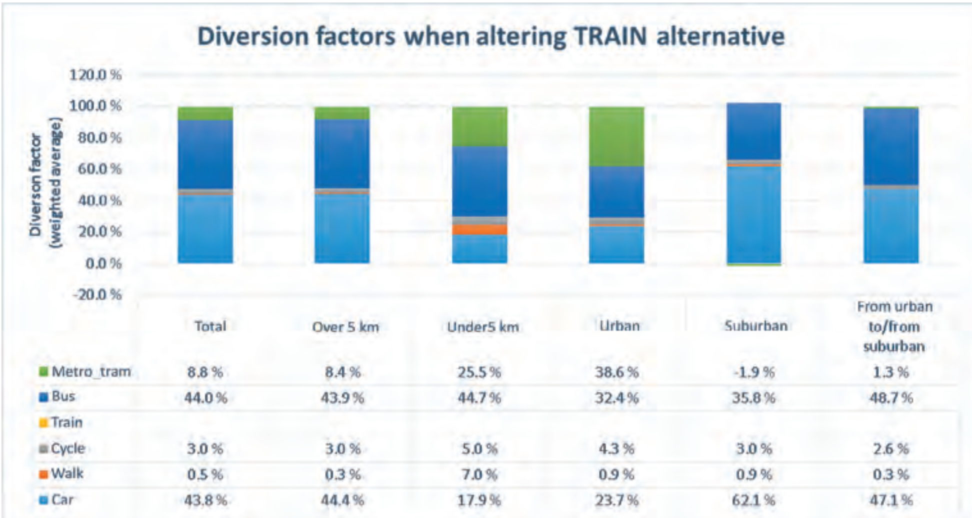


Figure 6: Diversion factors, total and by main categories, when train is altered.

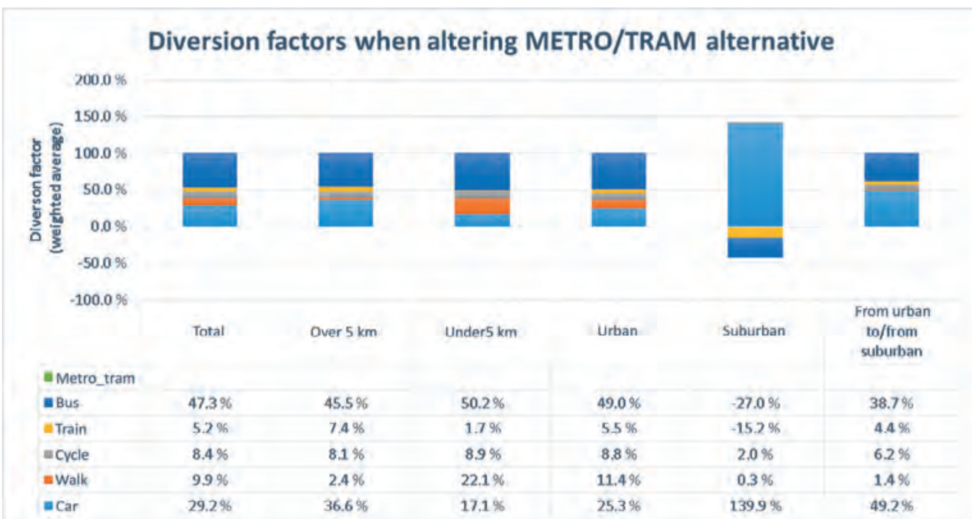


Figure 7: Diversion factors, total and by main categories, when metro/tram is altered.

5 REGRESSION MODELS

In this section, we present regression analysis on the simulated data. The purpose is to obtain information about which explanatory variables have a significant effect on DFs after controlling for other explanatory variables. It is convenient to run linear regression models even though those types of models do not guarantee that DFs (over a given altered mode) do add up to 100%.

It is important to note that simulated DFs for a given transport mode pair (altered and affected mode) are very similar within a given submarket. That is, the variation by type, direction and size of the policy change is very low. As a consequence, tests showed that the explanatory variables related to the direction and size (intensity) of change (if it is a −30%, −1%, 1% or 30% change) and the policy variable (price, travel time, etc.) are highly insignificant. In the following regression analysis, we look therefore only at 1% price increases. This implies a substantial reduction in the size of the data set. Note that without this adjustment, *t*-values for the other variables would be inflated. We apply weights to the likelihood function given by the market share of the affected transport mode in the given submarket.

We present two model versions (M1 and M2). In the former we include a generic coefficient for the number of available alternatives in the submarket. Diagnostic tests indicated a multicollinearity issue related to this variable (seemingly because of substantial correlation with some of the constant terms). After removing this variable (model M2), multicollinearity issue appears resolved. However, as models M1 give reasonable coefficient estimates, we opt to present results of M1 as well.

Table 5 shows estimation results for models with simulated DF as explanatory variables. The goodness-of-fit indicators of the estimation models are high, which is not surprising since many of the included explanatory variables were used to create the variation in simulated DFs in the first place.

Table 5: Estimated models.

Model index		***M*1***		***M*2**	
N		622		622	
Adjusted R^2		0.925		0.925	
Variable	**Type of variable**	**Value**	***t*-Stat**	**Value**	***t*-Stat**
Generic coefficients					
No. of available alternatives	Continuous (count)	−0.0289	−2.32		
Relative market share of affected mode	Cont. log-transformed	0.0064	2.49	0.0054	2.10
Coefficients for diversion factor towards car					
Distance (car)	Continuous (km)	0.0160	4.99	0.0146	4.62
Urban (car)	Dummy	−0.1184	−2.48	−0.1451	−3.12
Work-related (car)	Dummy	−0.0067	−0.26	−0.0088	−0.34
Coefficients for diversion factor towards train					
Distance (train)	Continuous (km)	0.0168	13.01	0.0162	12.76
Urban (train)	Dummy	0.0144	0.72	−0.0057	−0.31
Work-related (train)	Dummy	−0.0188	−1.17	−0.0195	−1.21
Coefficients when diversion factor towards bus					
Distance (bus)	Continuous (km)	0.0151	12.68	0.0145	12.43
Urban (bus)	Dummy	0.0563	2.80	0.0431	2.23
Work-related (bus)	Dummy	−0.0074	−0.44	−0.0078	−0.46
Coefficients when diversion factor towards metro/tram					
Distance (metro/tram)	Continuous (km)	0.0068	4.93	0.0063	4.62
Urban (metro/tram)	Dummy	0.2812	11.11	0.2791	10.99
Work-related (m/t)	Dummy	0.0004	0.02	0.0011	0.07

(*Continued*)

Table 5: (*Continued*)

Model index		***M*1***		***M*2**	
Coefficients when diversion factor towards walk					
Distance (walk)	Continuous (km)	−0.0338	−17.89	−0.0370	−28.72
Urban (walk)	Dummy	−0.2584	−12.78	−0.2806	−15.71
Work-related (walk)	Dummy	−0.0056	−0.36	−0.0089	−0.57
Coefficients when diversion factor towards cycle					
Distance (cycle)	Continuous (km)	−0.0008	−0.55	−0.0028	−2.51
Urban (cycle)	Dummy	0.0013	0.06	−0.0203	−1.13
Work-related (cycle)	Dummy	0.0285	1.83	0.0273	1.75
Constant terms for mode pair (altered mode → affected mode)					
Car → train	Dummy	0.1012	2.57	0.0297	1.21
Car → bus	Dummy	0.1804	5.59	0.1195	6.37
Car → metro/tram	Dummy	0.0881	2.00	0.0122	0.41
Car → walk	Dummy	0.8055	38.51	0.7743	48.19
Car → cycle	Dummy	0.2155	9.23	0.1793	10.31
Train → car	Dummy	0.3908	5.64	0.3467	5.18
Train → bus	Dummy	0.1322	2.75	0.0586	1.62
Train → metro/tram	Dummy	−0.0316	−0.61	−0.1076	−2.68
Train → walk	Dummy	0.7590	19.57	0.7240	20.20
Train → cycle	Dummy	0.1268	3.23	0.0874	2.46
Bus → car	Dummy	0.4444	7.17	0.3884	6.78
Bus → train	Dummy	0.0291	0.65	−0.0491	−1.67
Bus → metro/tram	Dummy	0.1176	2.27	0.0248	0.75
Bus → walk	Dummy	0.7084	20.69	0.6579	24.82
Bus → cycle	Dummy	0.1742	4.92	0.1189	4.53
Metro/tram → car	Dummy	0.4763	7.30	0.4307	6.90
Metro/tram → train	Dummy	−0.0037	−0.09	−0.0714	−2.27
Metro/tram → bus	Dummy	0.2665	5.62	0.1801	6.14
Metro/tram → walk	Dummy	0.7068	21.11	0.6643	23.64
Metro/tram → cycle	Dummy	0.1811	5.21	0.1338	4.74

*To facilitate understanding of the model, consider a situation where petrol prices increase and the task is to provide an estimate of the DF from car to bus. Assume there are four alternative modes so that the relative market share of bus/car is 0.666, travel distances are 10 km on average and we look at urban non-work trips. Using the model *M*3, we estimate $DF_{car \rightarrow bus}$ = 4*(−0.0289) + 0.0064*LN (0.6666) + 10*0.0151 + 0.0563 + 0 + 0.1804 = 0.2695 or 26.95%.

The variable 'Number of available alternatives' has a negative and significant impact on DFs. This is intuitive, as the DF towards a given mode should decrease – ceteris paribus – when more alternatives are available.

The variable 'Relative market share of affected mode' (i.e. relative to altered mode) is positive, meaning that a transport mode with a relatively high market share within a submarket attracts relative more travellers from the affected mode. This is expected given that the relative market share may capture the competitiveness of the affected mode in a given submarket and as such be an indicator of quality (that is, a proxy for the underlying LoS of the affected mode).

The coefficient estimates for distance, urban and work-related trip purpose resemble the general pattern that we already saw in Section 4. Trip distance plays the most prominent role in explaining differences in DFs across affected modes. Clearly, the DF towards walk reduces with increased trip distance. The dummy for urban trips is, as expected, significantly negative for DFs towards car and significantly positive for DFs towards metro/tram. The dummy for urban trips is also significantly negative for walk trips. This may be surprising at first glance but it must be noted that this result is after controlling for trip distance. The results for work-related trips are not significant. We observe a tendency towards cycling having higher DFs for work-related trips. This is likely to relate to the fact that cycling is impractical/inconvenient for some other trip purposes such as grocery shopping and escorting children.

The constant terms for the transport mode pair (altered → affected mode) resemble DFs given trip distance of zero and apply for the normalized segment (no-work suburban trips). The constant terms towards walk are naturally high, as walking is an attractive mode for very short-distance trips.

6 CONCLUSIONS AND DISCUSSION

Using our ‘model internal meta-analysis’ method, we have obtained the following results that conform with prior expectation:

1. DFs to walk are in general high but decrease rapidly with increasing distance
2. DFs to cycling tend to be higher for work-related trips
3. DFs to car and train increase with distance
4. The public transport internal DFs (i.e. between public transport modes) are rather high (typically around 50%)
5. DFs are in general lower, the higher the number of available transport modes
6. DFs are in general higher to transport modes with a relative high market share

While results 5 and 6 are more of theoretical interest, results 1–4 may have interesting policy implications. Oslo has a political goal that all future passenger transport growth is facilitated by walk, cycle or public transport. This implies a strong need for cross-modal substitution from car to other modes, since Oslo is experiencing high population growth and the underlying trend is for continued growth in car use. Taking a closer look at results 1–4, we may suggest the following implications for policy:

1. There is greatest potential to get car drivers to substitute to walk for short-distance travel. The DF from car to walk is found to be 64%. Policies that discourage short-distance car use (e.g. parking fees) may therefore be effective.
2. A rather high share of car trips seems to be substitutable with cycle. This appears especially true for work-related trips. In addition to restricting workplace parking availability and pricing, facilitating changing rooms, showers and safe bicycle parking at workplaces may be effective ways to encourage a shift away from car.
3. For longer distance travel in the Greater Oslo area, train is clearly the best substitute to car. Improving train options would therefore result in a relatively high share of long-distance car trips to be transferred to PT.
4. To avoid a strong ‘cannibalization’ between PT modes, it appears important to improve all public transport options. If only one PT option is improved, a relatively large share of new users will come from other PT alternatives.

Our methodological approach was motivated by learning more about variations in DFs (which vary greatly across studies) by holding the general context (study area) and the data and modelling methods fixed.

Important questions relate to the degree to which our results are method/model-driven, and to which results may be specific for the Oslo area and therefore not generalizable.

Result 1 is likely to be universally true. However, the degree is likely to vary between contexts. We regard our estimated values to be transferable as a proxy value for other cities.

On the other hand, result and implication point number 4 ('cannibalizing') may be influenced by the nesting structure of the underlying choice models that have a rather high nest parameter for the PT nest [25]. The nesting structure is defined by the researcher and the value of the estimated nest parameter is (indirectly) conditioned on the specification of utility functions such that high DFs may partly be a consequence of model building. However, the applied nesting structure was the one that fitted the survey data best and should – at least to some extent – represent the 'true' substitution pattern. Note that the high degree of substitutions between PT modes may also be specific to the Oslo area and may only apply to similar cities with an advanced, frequent and widespread public transportation network where several PT options 'overlap'.

Our methodological approach has a few weaknesses that need to be kept in mind. The underlying choice model does not calculate generated (or suppressed) transport which may impact on the absolute size of DFs towards other transport modes. Another important limitation is that we simulate symmetrical DFs for both *direction* and *size* of change, that is, our obtained DFs were close to identical for attribute changes of −30%, −1%, 1% and 30%, respectively. Furthermore, DFs with our method are widely unaffected by the type of attribute that is subject to change (price changes, travel time changes). This may or may not be the case in the real world. Despite these important caveats, we believe that this article has thrown new and to some degree transferable and generalizable light on the under-researched area of DFs and modal substitution.

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APPENDIX: DIVERSION OF EQN (4)

In multinomial logit models, we have $P_i = \frac{\exp(V_i)}{\sum_j \exp(V_j)}$ where the *V*s are generalized costs of the form $V = b_0 + b_1X_1 + b_2X_2 + \cdots$ and where the *X*s are specific to the alternatives *j*, and the *b*s may be generic or specific. For simplicity, assume that $V = a + bX$ without loss of generality. Recall that logit cross-price elasticities (denoted ε) for mode *i* are defined as $\varepsilon_{ii} = b \cdot X_i\,(1 - P_i)$ and $\varepsilon_{ij} = -b\,X_j\,P_j$ for a linear additive utility function (and similarly for *j*). Using the DF relationship between own- and cross-elasticities, we have $\varepsilon_{ij} = -\varepsilon_{jj}(P_i / P_j)\mathrm{DF}_{ij}$ and substituting in the formula for ε_{jj} and ε_{ij} we have $-b \cdot X_j \cdot P_j = -b \cdot X_j \cdot (1-P_j) \cdot (P_j / P_i)\,\mathrm{DF}_{ji}$ so that $\mathrm{DF}_{ji} = P_i/(1-P_j)$.

TRANSPORT ORGANIZERS' INTEGRATING ROLE IN CITY LOGISTICS

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ABSTRACT

The number of urban residents is growing by nearly 60 million people every year. With the growth of cities and urban population, cities are becoming more and more the centre of worldwide development. Being the centre of growth, cities have the additional responsibility to make development activities more sustainable and environmental friendly. Increasing urbanization requires new and innovative ways to manage the complexity of urban living and to target problems of energy consumption, resource management and environmental protection.

The present study is mostly based on investigating managers of transport and forwarding companies, public transport administrators and city board representatives within the Pomeranian region. Moreover, research is carried out on the analysis of practical solutions in the field of smart mobility solutions in European urban areas, documents of the European Commission and the publications prepared by industry associations. The theoretical part of the article is based on existing materials from public resources and author's research experience.

The study result is an authorial framework of goods' and people's transport organizer within metropolitan areas with conceptual modelling of their functions. Thus, the organizer's specialization does not depend on the subject of transportation, and their range comprehensively covers goods flows as well as passengers' transportation.

Analysis of solutions within goods and people flows within the metropolitan areas and the studies carried out on the basis of investigating key stakeholders shows that the best way within smart mobility concepts is employing specialized integrator – City Transport Organizer.

Keywords: city logistics, urban mobility, urban transport organizing

1 INTRODUCTION

In 2008, for the first time in history, more people lived in cities than in rural areas. It is estimated that by 2050 nearly two-thirds of the world's projected 9.7 billion people will be urban. Cities are becoming congested due to migration from rural areas, emigration from overseas as a result of globalization and the proliferation of industries and amenities. Due to the high rate of urbanization all over the world, the importance of the processes taking place within cities is increasing, thus the importance of city logistics is still growing. City logistics tends to be an important area, and it involves several levels of complexity. It consists of planning, coordination and controlling of logistic processes and various flows within urban areas. Logistic activities within cities, or especially city centres, generate external costs, therefore, looking for solutions improving the quality of life within cities is needed.

2 SMART CITY CONCEPT IN CITY MANAGEMENT

Facing the challenges of city management requires appropriate actions and appropriate strategies. The solution may be the application of different tools within smart city concept.

The birth of smart city idea is rooted in 'the creation and connection of

- social capital;
- information; and
- communication technology infrastructure

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in order to generate greater and more sustainable economic development and better quality of life within the urban areas' [1].

Smart cities are understood as '…cities that use information and communication technologies (ICT) to be more intelligent and efficient in the use of resources, resulting in cost and energy savings, improved service delivery and quality of life, and reduced environmental footprint–all supporting innovation and the low-carbon economy' [2].

A Smarter City systematically creates and encourages innovations in city systems that are enabled by technology; that change the relationships between the creation of economic and social value and the consumption of resources; and that contribute in a coordinated way to achieving a vision and clear objectives that are supported by a consensus among city stakeholders.

To conclude, it's likely that the following generic objectives should be considered and adapted in that process:

- 'A Smarter City is in a position to make a success of the present: for example, it is economically active in high-value industry sectors and able to provide the workforce and infrastructure that companies in those sectors need.
- A Smarter City is on course for a successful future: with an education system that provides the skills that will be needed by future industries as technology evolves.
- A Smarter City creates sustainable, equitably distributed growth: where education and employment opportunities are widely available to all citizens and communities, and with a focus on delivering social and environmental outcomes as well as economic growth.
- A Smarter City operates as efficiently & intelligently as possible: so that resources such as energy, transportation systems and water are used optimally, providing a low-cost, low-carbon basis for economic and social growth, and an attractive, healthy environment in which to live and work.
- A Smarter City enables citizens, communities, entrepreneurs & businesses to do their best; because making infrastructures Smarter is an engineering challenge; but making cities Smarter is a societal challenge; and those best placed to understand how societies can change are those who can innovate within them.
- A Smarter City harnesses technology effectively and makes it accessible; because technology continues to define the new infrastructures that are required to achieve efficiencies in operation; and to enable economic and social growth' [3].

Smart city concept includes six dimensions:

- 'smart government;
- smart economy;
- smart mobility;
- smart environment;
- smart citizens;
- smart living' [4].

Although the idea of smart city was initially implemented in many cities by pursuing a sustainable energy policy, now according to the opinions of the smart urban experts, intelligent transport is essential to improving the quality of life of urban residents. So for the needs of this article, just smart mobility area will be analysed.

Smart mobility means ICT supported and integrated transport and logistics systems within the urban areas. Its priorities focus on

- 'sustainable, safe and interconnected transportation systems within the city regarding passengers and goods transportation;
- promotion of clean and non-motorised options of transportation of goods as well as passengers;
- real-time information systems;
- transport and logistics manager engagement responsible for the flows within the urban areas' [5].

3 CITY LOGISTICS ESSENTIALS

Caring for the flow of goods and passengers through integrated urban logistic strategies should be a determinant of urban management. Urban logistics is a specific area where smart solutions are often used. Benefits in this regard are felt both by residents, entrepreneurs, administrators and tourists. As a result of streamlining urban flows, improved traffic flow, increased mobility and increased quality of life in the city can be observed. Furthermore, the reduction of air pollution, the reduction of noise, the shortening of travel time, the improvement of road safety and the reduction of road infrastructure degradation are of great importance.

It is difficult to find a common definition of city logistics in expert literature [6]. Various terms are used to refer to the general concept of transportation of goods, people and waste in urban areas: 'urban goods movement', 'urban logistics', 'urban freight transport' or 'urban passengers transport'. The exact definitions of these terms differ slightly as to what is and what is not included [7].

A simple definition of urban logistics states that it is planning, implementation and monitoring of economic efficiency and effectiveness of people, cargo and relevant information flows in urban areas in order to improve the quality of citizens' life. The most precise definition says it is 'the process for total optimization of logistics and transport activities by private companies with the support of advanced information systems in urban areas considering traffic environment, traffic congestion, traffic safety and energy savings within the framework of market economy' [8].

The system of urban logistics should be understood as a deliberately organized set of elements such as stakeholders, infrastructure, regulatory standards, tariffs and relationships between them, which are involved in the process pertaining to the flows of people, cargo and relevant information in urban areas. Providers of urban logistic services are expected to be one of the most important elements of the whole system, and they should offer high-quality and reasonable prices of their delivery services in the environment of congested urban areas [9].

4 URBAN MOBILITY IMPROVEMENT CONCEPTS

The expansion of urban structures, the increase in the number of urban population and related flows gradually contribute to the deterioration of life quality in urban areas. Therefore, some improvement of various processes is necessary. The priorities of transport policy of the European Union are defined on the basis of similar assumptions. They are oriented towards the promotion and popularization of solutions which are aimed at the improvement in life quality in urban areas through the achievement of the following objectives [10]:

- rational use of individual means of transport;
- improvement in handling the delivery transport in city centres;
- use of smart technologies in the means of transport, infrastructure and traffic management;
- exchange of good practice referring to practical solutions for city logistics.

Practical solutions applied in the European countries as regards the improvement in city logistics may relate to the following areas [11]:

- land-use planning;
- infrastructure;
- market-based solutions;
- new technologies.

Within the scope of land-use planning measures, different practical solutions can be distinguished. Most of them are applied in European countries. They can refer to [11]:

- restricted access to certain areas, based on different criteria for vehicles;
- time slots – solution refers to situation when certain vehicles can enter certain streets;
- exclusivity zones – it consists on limiting of the number of transporters that can perform deliveries;
- adapting on-street loading zones;
- nearby delivery areas.

A more proactive approach is to incorporate freight planning into proper management and to create infrastructure by identifying areas of conflicts between freight activities and other land uses. The initiatives that are needed for proper infrastructure are the following [12]:

- urban distribution centres – collecting shipments in a specialized warehouse at the edge of the city where they are consolidated before last mile transport;
- direct injection – solution within bringing goods directly in the city using alternative transportation means;
- dedicated parking spaces for trucks – preparing special lanes for loading and unloading trucks or letting them to use bus lanes during certain times of the day;
- e-commerce pick-up points – enabling transporters to deliver parcels to single locations without having to go from door to door.

The next group of measures is based on market solutions. They come as the most common option adapted by the local authorities to reduce externalities of road transport. They can be divided into [12]:

- urban congestion charges for certain roads or areas to incentivize car users to reduce traffic in those areas;
- subsidies, tax reductions, incentives to foster the implementation of infrastructure, equipment or technology levers.

A well-known solution, that is, to make mobility of goods in urban areas more sustainable, is based on new technologies. The role of new technologies in the optimization of urban logistics can be very diverse and can be applied in different solutions, such as [12]

- intelligent transport system;
- Real-time information system;
- alternative transportation means;
- crowd-sourced delivery and transport solutions.

Most of the above-mentioned practical solutions are successfully applied in various European countries with the help of the European Union funds. Moreover, different solutions and measures aimed at improving flows within urban areas can come from the stakeholder engagements. Stakeholder engagement is becoming increasingly recognized as an important part of any decision-making process. Successful collaborative partnerships between particular stakeholders can lead to the formulation of high-impact freight strategies that consider logistic needs of the city, businesses, transport operators and local residents. Given the complexity of the participative approach, which includes all of the above, the involvement of different players should be stimulated and maximized from the very beginning of the planning stage.

The most common tools applied to involve stakeholders are [11]

- freight quality partnerships are to bring together the public and the private sector to discuss problems, identify and implement solutions within freight transport activities;
- freight advisory boards and forums are opportunity for stakeholders to meet and discuss challenges and chances of the freight space within the city;
- city logistics manager (CLM) function.

The function of CLM is designed to reduce demand in relation to the mobility of goods in urban areas. The main functions of CLM concerns

- ‘classification and analysis of the situation characteristic of an urban context;
- discussion and sharing with the key local actors;
- definition of shared intervention strategies to apply to the surveyed urban context;
- preliminary, definitive and executive planning of the urban freight logistics mode;
- monitoring and evaluation of impacts of the planned and implemented urban freight transport modes’ [11].

The mobility manager represents real intermediaries between the various local stakeholders and the public authority; their task is to reconcile the needs and demands of different companies, businesses and associations with those of the public authority and to select proposals for shared actions and plans.

5 TRANSPORT ORGANIZERS – THEIR INTEGRATING ROLE IN CITY LOGISTICS

City logistics concept comes from some well-established and firm logistic principles such as

- coordination of activities related to the systemic approach,
- orientation towards integrated flows and
- consideration of problems viewed from a holistic point of view.

Considering the case in which a manager responsible for city logistics is appointed for a particular administrative area, it may facilitate the achievement of the assumed aims of city logistics, which are additionally promoted in the European Union transportation policy. It is assumed that disintegration lowers the efficiency of transport, and it introduces irrational distribution of transport tasks; in this way, it contributes to the generation of costs which are too high or unnecessary. Integration of transport may have various forms, scopes and levels. The arguments for the necessity of integration are the integrating concepts referring to the organization of freight transport and the organization of passenger transport. Their scope incorporates some specified fields in the transport sector; however, they differ in terms of transported objects, handled by particular organizations which specialize in such services. Some concepts refer to the integration in the spatial aspect and to the integration of transport in the regional aspect. All the integrating concepts feature a superior entity, responsible for the course of transport processes, synchronization and coordination which are required during such processes.

Therefore, the objectives of city logistics are quite difficult to achieve in terms of the improvement in flows in urban areas, without their coordination provided by a specialized entity [11]. Such an entity should be a coordinator, an organizer of the integrated system of urban transport, which would not differentiate its operation in terms of transported objects, but which would comprehensively make all its implemented functions universal in the administrative area in which it operates; such an entity should refer to the concept of the manager of city logistics. By assumption, city logistics is an element of the state economic policy, and one of its permanent characteristics is the long-term intervention of the state. In the model of city logistics, the solutions that involve the public administration as the main stakeholder, which offers its own funds, are widely preferred. Considering that fact, an organizer of city logistics should be employed by the administrative authorities of particular urban areas [13].

While implementing such aims and facing challenges related to the improvement in flows in urban areas, an organizer of city logistics should strive for transport integration. The aims assumed for the operation of such an entity should be the following [14]:

- development of an integrated system of freight and passenger transport;
- finding possibilities for the implementation of the transport policy assumptions;
- rationalization of the transport system costs;
- satisfaction of freight shippers' and public transport of passengers' needs;
- providing services of higher quality than in the situation of transport disintegration; and
- improvement of the competitive position of public transport in regard to individual transport.

A wide scope of activities implemented by the organizer of the integrated transport system requires this entity to approve solutions that have been precisely developed for the particular area. The variety of management fields, in which the organizer of the integrated system of transport is supposed to operate, gives the possibility to define some universal problems for the most areas of such operation. However, during the implementation of the specific activities, it is necessary to consider the specific character of the particular transport sectors. A more precise definition referring to the operation of such an entity requires a division of its functions into the functions that are implemented during its current operation and the functions that are performed within a strategic long-time perspective.

Furthermore, while dividing the functions of the organizer into operational and strategic, it is possible to state that the longer the time perspective for a particular task is, the more possibilities appear and the higher willingness of the organizer becomes to make its approach more universal. Analogically, the more a particular activity is related to the operational function, the higher the necessity becomes to adopt an individualized approach. The operational functions of the organizers include:

- development and provision of information about transport functioning;
- promotion of services;
- development of schedules for regular connection lines;
- pricing services;
- distribution of services;
- supervision over the proper implementation of contracts.

The strategic functions include:

- construction of integration hubs;
- surveying the demand and requirements for transport;
- provision of proper conditions for transport functioning/standardization of services;
- planning the development of transport.

6 CITY LOGISTICS TRANSPORT ORGANIZERS – THEIR FUNCTIONS IN CITY LOGISTICS IMPROVING

The above-mentioned functions performed by the organizer contribute – to various extent – to the achievement of the main aim, which is namely the improvement in freight and passenger flows in urban areas.

To verify his functions in terms of such contributive influence, some criteria have been assumed as regards their adequacy, efficiency and effectiveness. Considering the context of the influence exerted by the functions of the organizer on the improvement in urban flows, the adequacy criterion is related to the scope of the organizer's operation, the competences required to perform the particular functions and all the required and necessary tools to do it. The efficiency refers to the real outcomes that result from the performed function in relation to the intended aims. Thus, the measure of efficiency is determination of how close it is for the organizer to achieve the aims that have been assumed for a particular cycle of operation. The effectiveness is related to the performance of the aim functions and with the development of the most advantageous relations between the incurred expenses and the obtained results. The results of the research study and analysis allow us to characterize the function data and to determine to what extent they meet the above-mentioned criteria.

7 SUMMARY

As a result of the activities performed by the operator of the integrated system of transport, it is possible to achieve considerable benefits, not only for the service recipients but also for the whole structure of the transport system. The system benefits may be related to the sustainable development of transport, which takes place in accordance with the pro-ecological requirements and the economic growth of the particular area. The benefits for service recipients take the following forms: the higher level of the above-mentioned services that are offered within the frame of the integrated system of transport, an increase in the attractiveness of the transport offer, better prices and higher quality, lower transport costs, an access to a comprehensive offer provided by the organizer and an access to the detailed information on transport possibilities.

Table 1: Function of transport organizer meeting the objectives of city logistics improvements (source: own elaboration).

Function	Adequacy	Efficiency	Effectiveness
Information about services	+*	+	−+
Promotion of services	−+	−+	−
Development of schedules for regular connection lines	−+	+	+
Pricing of the services	−+	+	−+
Distribution of the services	−+	+	−+
Supervision over the operators	+	+	−+
Construction of integration hubs	+	+	+
Surveying the demand and requirements for transport	−+	−	−
Standardization of services	+	+	−+
Planning the development of transport	+	+	+

Source: *'+' – a function that fully meets the objectives of the improvement in city logistics; – a function that meets the objectives of the improvement in city logistics to a large extent; '−+' – a function that meets the objectives of the improvement in city logistics to a little extent; '−' a function that does not meet the objectives of the improvement in city logistics.

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DO POLICY MEASURES IN FACT PROMOTE ELECTRIC MOBILITY? A STUDY ACROSS 20 COUNTRIES

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ABSTRACT

In a 2015 study, policy measures to promote electric mobility were examined with regard to their acceptance by consumers in 20 countries on five continents. Results of a choice-based conjoint analysis showed that people appreciate monetary incentives; however, the application of the Kano method to detect dissatisfaction with missing features revealed that charging networks are absolute must-haves. In the same 20 countries, the present article examines the actual effects of three kinds of policy measures: monetary incentives, traffic regulations in favour of electric vehicles (EVs), and investments in charging infrastructure. The outcome variable was the percentage of new registered EVs in 2016. All policy measures had positive direct effects; however, the number of existing charging stations as a moderator increased the effect of monetary measures over proportionately. The widespread uptake of EVs has been challenged by the problem that people do not accept EVs as long as the number of charging stations is insufficient, and the low number of EVs has not stimulated sufficient demand for charging stations yet. The results demonstrate how this 'chicken or the egg' dilemma will be resolved over time as soon as a sufficient number of charging stations are available. Because the effects of monetary measures and charging stations reinforce each other and the number of charging stations is accumulative, governments will be able to offer fewer and fewer monetary incentives to produce the same promoting effects.

Keywords: charging infrastructure, electric vehicles, monetary incentives, policy measures.

1 INTRODUCTION

Although the global share of electric vehicles (EVs) has been rising over the past years, their uptake is still relatively low in most countries around the world [1]. In order to support more widespread use of EVs, various governments have begun to offer incentives, such as financial subsidies or tax exemptions for new EV purchases, traffic regulations favouring EVs, as well as investments in the charging infrastructure [1, 2]. The types and extents of such policy measures, however, differ significantly across countries, as does the share of EVs in the respective markets.

Regarding the effects of various types of policy measures, the results of Lieven's [3] 2015 study across 20 countries showed that monetary grants are the most appreciated incentives for individuals to purchase an EV. In addition, although charging networks on freeways are assumed to be absolute necessities, the free use of bus or fast lanes and city parking are not considered attractive incentives. Furthermore, the study showed that potential EV buyers prefer a charging network over a net cash grant of $6,000. Thus, investment in charging infrastructure is probably more effective for promoting the uptake of EVs than the provision of cash grants.

Referring to this study, this article aims at further investigating these empirical findings by comparing them with actual data from 2016. Specifically, the study examines how and to what extent numerous factors, such as monetary incentives, traffic regulations, investments in infrastructure, and the number of charging stations, influence the market share of EVs. A similar study published by Sierzchula et al. [4] pointed out that financial incentives and charging infrastructure are positively correlated with EV market shares; however, there

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was no evidence of a causal effect. As the authors used data from 2012 with only very small EV market shares, in the current study, these market shares are significantly higher after four years (e.g. Norway in 2012 was 3%, in 2016 nearly 30% of new car registrations). The chance of finding true causal effects thus should be higher in this study. Furthermore, this study incorporates empirical data from research in the respective 20 countries assessing people's average driven mileage per day and dissatisfaction when specific policy measures are not available. Results have a clear message to policy makers regarding effective and efficient measures to promote electric mobility.

2 METHOD AND PROCEDURE

This study uses secondary data collected from several sources for the year 2016. The dependent variable in the subsequent analyses was the percentage of pure EVs and plug-in hybrid electric vehicles (PHEVs) registered during 2016 compared to the total number of registrations in the respective 20 countries (Australia, Belgium, Brazil, Canada, Switzerland, China, Germany, France, Hong Kong, India, Italy, Japan, Korea, the Netherlands, Norway, Russia, Taiwan, Great Britain, the United States [USA], and South Africa). The number of total vehicle sales was derived from one of the earliest motor vehicle manufacturer organizations, founded in 1919 as the Organisation Internationale des Constructeurs d'Automobiles (OICA [5]). These data distinguish between passenger cars and commercial vehicles. Only the number of passenger cars was used in this article because small trucks or pick-ups are not in a competitive position with passenger cars. This distinction is particularly important for the United States where the total number of all vehicles registered is as high as 17.9 million, but the number of passenger cars is only 6.9 million. With 158,212 EVs sold in the USA in 2016, the proportion of EVs in this study is 2.3% which is significantly higher than in other reports in which the total number of vehicles includes commercial cars. Information about EVs sold in 2016 was obtained from the Swedish consulting firm EV-Volumes [6]. These data list all vehicles by brand and model. PHEVs and EVs were considered. This might be a bias towards higher market penetration of electric mobility. However, the data include all consumers who are interested in electric propulsion. It can be expected that many of those buying PHEVs now will switch to EVs as soon as the range is long enough for the latter. A recent study in the USA with 204 participants showed that a majority of 57% ($\chi^2 = 3.9$, $P < 0.05$) would prefer a pure EV over a PHEV as soon as the EV has a range of 300 miles.

Assessing monetary policy measures was more complicated in particular because even within countries the measures may not be similar in all regions. There exist many ways to provide incentives, such as direct subsidies or road tax exemptions. Some countries raise one-time taxes on the registration of vehicles which can be very high, as in Norway. All monetary measures were added for a longer period of several years. Even countries with only small one-time monetary incentives show a reasonable total monetary measure, such as Switzerland, where only a low yearly road tax must be paid instead of hundreds of Swiss francs for regular cars. Within ten years, this total adds up to 5,000 (note that the US dollar, the euro and Swiss francs are treated as being of equal value). Investments in infrastructure and traffic regulations, such as free use of fast or bus lanes, were expressed with dummy variables.

Numbers of charging stations were derived from several publications. However, sometimes whether figures mean charging locations (with one or more single charging points) or whether figures represent single plugs was indeterminate. Finally, comparing several sources

Table 1: Data for 20 countries.

Country	PHEVs and EVs sold in 2016	Total sales 2016	**EV market share 2016**	**Monetary measures**	**Infrastructure**	**Traffic regulation**	Charging stations total	Population in millions	**Chargers per 1 million population**	Highway km	**Stations per highway km**	**National purchase power**	**Daily driving distance in miles**	**Range anxiety (1=low; 6=high)**
AU Australia	1,433	927,274	**0.15%**	**0**	**0**	**0**	60	24,642	**2.43**	1,700	**0.04**	**103.9**	**28.70**	**3.06**
BE Belgium	9,598	539,519	**1.78%**	**6,500**	**1**	**0**	1,715	11,444	**149.86**	1,763	**0.97**	**85.9**	**34.60**	**3.65**
BR Brazil	48	1,676,722	**0.00%**	**500**	**0**	**0**	60	211,243	**0.28**	11,000	**0.01**	**36.2**	**42.98**	**1.52**
CA Canada	10,842	661,088	**1.64%**	**6,000**	**1**	**1**	4,465	36,626	**121.91**	16,900	**0.26**	**99.5**	**30.63**	**3.47**
CH Switzerland	5,654	317,318	**1.78%**	**5,000**	**0**	**0**	3,828	8,454	**452.80**	1,361	**2.81**	**105.9**	**32.85**	**3.96**
CN China	350,578	24,376,902	**1.44%**	**6,000**	**0**	**2**	81,000	1,388,233	**58.35**	97,355	**0.83**	**23.5**	**30.73**	**3.49**
DE Germany	28,079	3,351,607	**0.84%**	**4,000**	**0**	**0.2**	24,667	80,636	**305.91**	12,845	**1.92**	**100.0**	**32.52**	**4.27**
FR France	34,205	2,015,177	**1.70%**	**7,000**	**1**	**0**	16,000	64,939	**246.39**	11,392	**1.40**	**80.3**	**33.08**	**4.20**
HK Hong Kong	1,367	41,600	**3.29%**	**8,000**	**0**	**0**	1,500	7,402	**202.65**	100	**15.00**	**71.8**	**41.94**	**2.75**
IN India	1,023	2,966,637	**0.03%**	**3,000**	**0**	**0**	328	1,342,513	**0.24**	1,208	**0.27**	**9.5**	**37.89**	**2.67**
IT Italy	3,463	1,824,968	**0.19%**	**5,000**	**1**	**0.5**	2,205	59,798	**36.87**	6,661	**0.33**	**69.7**	**31.48**	**1.93**
JP Japan	23,438	4,146,459	**0.57%**	**5,000**	**0**	**0**	40,000	126,045	**317.35**	7,383	**5.42**	**70.2**	**19.11**	**3.09**
KR Korea	6,108	1,533,813	**0.40%**	**5,000**	**0**	**0.5**	1,270	50,705	**25.05**	4,044	**0.31**	**56.5**	**27.31**	**3.57**
NL Netherlands	23,129	382,825	**6.04%**	**20,000**	**1**	**0**	28,246	17,033	**1,658.31**	2,808	**10.06**	**97.6**	**32.00**	**3.64**
NO Norway	45,685	154,603	**29.55%**	**25,000**	**2**	**3**	8,734	5,331	**1,638.40**	664	**13.15**	**138.7**	**18.54**	**4.03**
RU Russia	416	1,239,680	**0.03%**	**2,000**	**0**	**0**	200	143,375	**1.39**	1,400	**0.14**	**42.5**	**55.24**	**2.46**
TW Taiwan	2	206,092	**0.00%**	**2,000**	**0**	**0**	360	23,405	**15.38**	1,335	**0.27**	**60.0**	**23.07**	**2.88**
UK	39,351	2,692,786	**1.46%**	**6,000**	**1**	**1**	12,320	65,511	**188.06**	6,016	**2.05**	**81.6**	**38.26**	**3.26**
USA	158,212	6,872,729	**2.30%**	**7,500**	**2**	**1**	42,918	326,474	**131.46**	75,008	**0.57**	**109.3**	**33.46**	**3.35**
ZA South Africa	159	361,289	**0.04%**	**0**	**0**	**0**	40	55,436	**0.72**	1,927	**0.02**	**25.0**	**50.88**	**2.84**

Sources: Sales figures EVs: EV-Volumes [6]; sales figures total: OICA [5]; monetary measures: EAFO [2], van der Steen et al. [11], IEA [12], Benvenutti et al. [13], Mock and Yang [14], promotion of electric vehicles in Hong Kong [15], Rokadiya and Bandivadekar [16], JAMA [17, 18], Hao et al. [19], Kim and Yang [20], Gimadi [21], Maurer [22]; infrastructure: EAFO [2], van der Steen et al. [11], IEA [12], traffic regulation: EAFO [2], IEA [12], Kim and Yang [20], Zhu et al. [23]; charging stations: OECD/IEA [1], EAFO [2, 9], Chargehub [7], PlugShare [8], EPD [15]; population: Worldometers [10]; highway km: NationMaster [24], national purchase power: Laenderdaten [25]; daily driving distance: Lieven [3], range anxiety: Lieven [3].

[1, 2, 7–9] led to reasonable results that represent at least the prevalence of such infrastructure. The quotient between the number of charging stations and the total population [10] can be seen as a measure of dissemination in the respective countries.

The same holds for the number of charging stations per highway kilometre [24]. In addition, the national purchasing power indices were added to the analyses [25]. From a worldwide survey in the respective 20 countries, the daily driving distances were known, as well as drivers' range anxiety [3]. The complete set of data is depicted in Table 1.

The data were analysed in a simultaneous equation model with partial least squares regression (PLS [26]). The respective model is depicted in Fig. 1. The bold variables in Table 1 were included in the model and data from a worldwide study with 8,147 participants in the above-mentioned countries [3]. These were the results of a conjoint analysis with respondents' utilities of monetary measures, traffic regulations such as free use of bus lanes or city parking and charging infrastructure. Furthermore, dissatisfaction indices derived from the Kano model [27] were included in the PLS regression. These indices measured the degree to which respondents were disappointed if these measures were not available. In Fig. 1, the interaction term of monetary measures and number of charging stations is included. In the initial model, this was not the case.

3 RESULTS

We do not report significances in the PLS model because the limited number of cases (20) makes the *t*-values quite low. However, the significance of the bivariate correlations can be seen in Table 2.

We report Cohen's effect size f^2 [28] which is independent of sample size [29] and is an evaluation of the increase in the coefficient of determination when the respective variable is included. This R^2 value is a measure of the portion of the dependent variable's variance that could be explained. In the initial model without interaction terms, all three utilities positively influenced the respective measures ($\beta_{\text{Monetary}} = 0.29, f^2 = 0.11$; $\beta_{\text{Traffic Regulations}} = 0.15, f^2 = 0.02$; $\beta_{\text{Infrastructure}} = 0.22, f^2 = 0.09$). The effect of utilities on measures means that the higher the consumers' utility of policy measures, the more such policy measures exist. This measure reveals governments' willingness to follow their populations' needs and requests. This result is supported by a decline in dissatisfaction with stronger measures ($\beta_{\text{Monetary}} = -0.56, f^2 = 0.45$; $\beta_{\text{Traffic Regulations}} = -0.36, f^2 = 0.15$; $\beta_{\text{Infrastructure}} = -0.09, f^2 = 0.01$).

As can be expected, national purchase power positively supports policy measures ($\beta_{\text{Monetary}} = 0.73, f^2 = 0.78$; $\beta_{\text{Traffic Regulations}} = 0.29, f^2 = 0.09$; $\beta_{\text{Infrastructure}} = 0.63, f^2 = 0.72$). According to the R^2 values, 42% of the variance in the monetary measures can be explained, 12% of the variation in the traffic regulations by 12%, and 45% of the variation in the infrastructure investments.

Two of the three measures positively affect the EV market share ($\beta_{\text{Monetary}} = 0.73, f^2 = 0.37$; $\beta_{\text{Traffic Regulations}} = 0.19, f^2 = 0.09$). The number of charging stations seems to mediate the direct effect of infrastructure measures ($\beta_{\text{Chargers}} = 0.16, f^2 = 0.05$). This mediation indicates that infrastructure measures increase the number of charging stations, which, in turn, increases the EV market share. A look at the control variables reveals that the more miles people drive the lower their range anxiety ($\beta_{\text{Distance}} = -0.43, f^2 = 0.23$). This range anxiety, however, increases the number of installed charging stations ($\beta_{\text{Range Anxiety}} = 0.27, f^2 = 0.09$).

Eighty-nine per cent of the variation in the EV market share was explained in this model ($R^2 = 0.89$). A further examination included the interaction term of monetary measures and the number of installed charging stations as can be seen in Fig. 1. This interaction suppresses

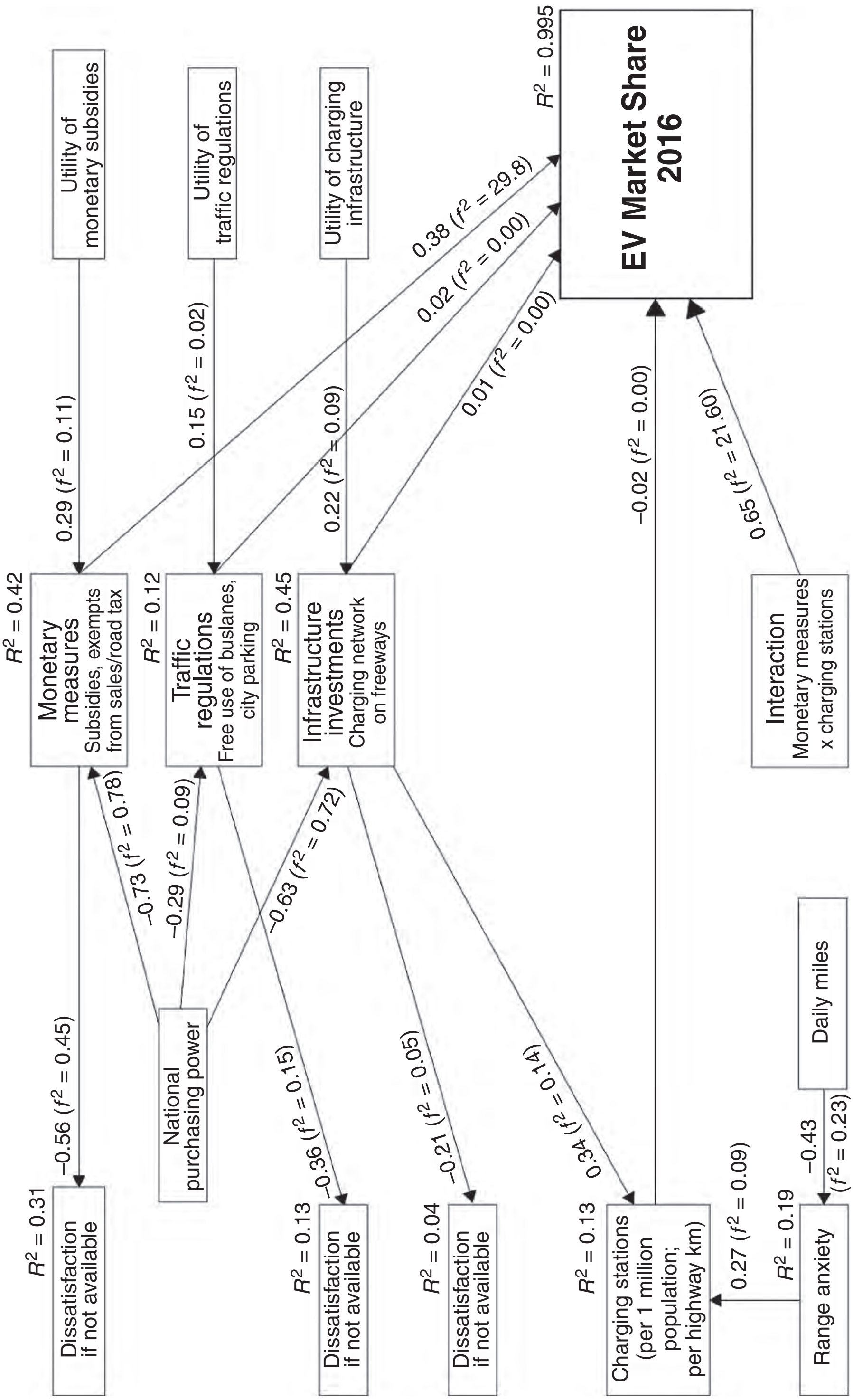

Figure 1: Partial least squares model.

Note: f^2 is Cohen's effect size (0.02 for a small, 0.15 for a mid-size, and 0.35 for a strong effect).

Table 2: Correlations.

	Monetary measures	Infrastructure measures	Traffic regulations	Charging stations per 1 million population	Charging stations per kilometre	Purchasing power	Range anxiety	Daily miles driven
EV market share	0.932***	0.587*	0.734***	0.786***	0.659**		0.352	
Monetary measures		0.703**	0.741***	0.796***	0.711***	0.596**	0.473*	
Infrastructure			0.561*	0.498*	0.245	0.629**		
Traffic regulations				0.405*	0.273	0.314		
Charging stations per 1 million population					0.724***	0.573*	0.445*	
Charging stations per kilometre						0.412*		
Range anxiety								–0.433*
National purchasing power							0.576**	

Note: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.10$.

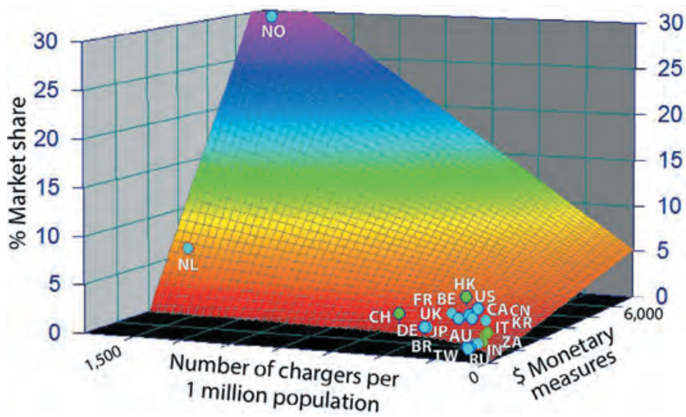

Figure 2: Percentage of EVs in 20 countries (interaction included).

the effect of traffic regulations and the direct effect of the number of charging stations. The direct effect of monetary measures is reduced ($\beta_{\text{Monetary}} = 0.38$, $f^2 = 0.30$). The interaction, however, positively affects the percentage of EVs ($\beta_{\text{Interaction}} = 0.66$, $f^2 = 0.22$). This modification results in an explained variance in the outcome variable (EV percentage) of nearly 100%.

How important the interaction term is can also be seen from Fig. 2. In the three-dimensional space, the EV percentages nearly fit the function exactly, including the interaction term ($R^2 = 0.993$):

$$\text{EV\%} = \beta_0 + \beta_1 \cdot M + \beta_2 \cdot N + \beta_3 \cdot M \cdot N \quad (1)$$

where M is the monetary measures and N is the number of charging stations, $\beta_0 = 1.23$; $\beta_1 = 2.77$, $p < 0.001$; $\beta_2 = -0.45$, n.s.; $\beta_3 = 1.90$, $p < 0.001$. In the interaction model (Fig. 2), the mere effect of monetary measures is much smaller, as is the effect of charging stations (which is slightly negative but is not statistically significant). An important increase in the EV percentage is explained by the interaction term.

4 DISCUSSION, LIMITATIONS AND CONCLUSION

This study with real data is in line with the empirical results. Lieven [3] pointed out that monetary policy measures are appreciated by consumers; however, charging infrastructure is a must-have. Analyses of the actual percentage of EVs registered in 2016 show that the interaction term contributes significantly. Thus, the finding from consumer research that governments should not concentrate on monetary measures only but should also include infrastructure projects was supported in this study.

This finding is even more important because investments in infrastructure are more efficient. Allowing EVs free use of bus lanes or city parking is effective but is not efficient because of the congestion effects with an increasing number of EVs. Because monetary measures are paid individually, no increasing efficiency will occur over time. Installing charging stations, however, becomes increasingly efficient because they not only are used by today's EV drivers but also will be used by future EV drivers. Thus, the effects of investments in charging infrastructure sum over time while monetary measures are paid once with a one-time effect and do not sum. Briefly, a monetary incentive attracts only one EV buyer while the installation of a charger attracts many potential EV buyers. Based on the example in Lieven [3], with a US government budget of $3 billion, such as in the 2009 Cash for Clunkers programme, it would be wiser to install 6,000 fast chargers along interstate highways and pay an incentive of $3,000–700,000 EV buyers than to give approximately 333,000 EV buyers a grant of $9,000.

The fact that policy measures are stronger in countries where consumers' perceived utility of such measures is higher and dissatisfaction about missing measures is lower emphasizes the plausibility of the model and the data. The strong effects that can be seen in Figs 1 and 2 point towards a possible limitation of this study concerning problems caused by outliers. Such outliers could be the Netherlands and – above all – Norway. Outliers can have serious distortion effects on regression results. Especially, outliers can represent the only reason a significant causal effect is falsely identified. However, Norway is not an outlier in the classical sense as a randomly outside situated data point. It is more the political will of Norway's government than a mere coincidence that the percentage of EV registrations was so high in 2016. Norway offers numerous tax incentives, rebates, subsidies and loosening of traffic restrictions to EV owners [30, 31]. Almost one-third of all new registered cars in Norway were EVs. From this outstanding percentage, it can safely be concluded that this result is causally induced by the magnitude of Norwegian policy measures. Thus far, this study could enhance Sierzchula et al.'s [4] warning about the uncritical acceptance of a causal relationship between financial incentives, charging infrastructure and EV market share. According to our data, these causal effects exist. The same holds in some way for the Netherlands. The question remains, how the model would perform without these two exceptional examples. To examine this point, Norway and the Netherlands were removed from the sample, and the regression from eqn (1) was repeated including the interaction term. The regression itself was statistically significant ($R^2 = 0.84$, $F(3, 14) = 24.46$, $p < 0.001$) with statistically significant positive coefficients ($\beta_0 = 1.69$; $\beta_1 = 3.92$, $p < 0.001$; $\beta_2 = 1.68$, $p < 0.01$; $\beta_3 = 5.46$, $p < 0.01$; Fig. 3). This means that even if one assumes Norway and the Netherlands are outliers, the main finding of this study holds with significant and positive causal effects of monetary measures and infrastructure investments on EV market share.

This study enhances the existing literature as real data in 20 countries from 2016 supported preferences previously stated in these countries in 2014. Results are promising and could

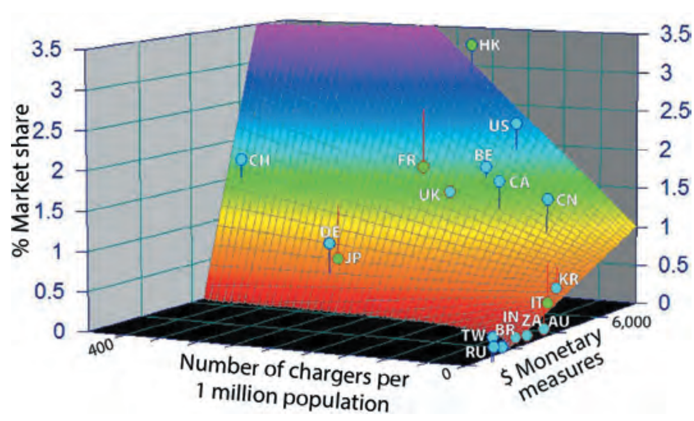

Figure 3: Percentage of EVs excluding Norway and the Netherlands (interaction included).

encourage governments to promote the acceptance of electric mobility with a balanced policy in favour of direct financial subsidies combined with intense support for charging infrastructure. This policy does not necessarily have to be cost intensive as regulations could encourage building owners to implement a sufficient number of charging stations, particularly in metropolitan areas. The direct and interaction effects will increase the percentage of EVs in these countries even more.

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ENVIRONMENTAL IMPACTS OF SPRAWLED RESIDENTIAL SETTLEMENTS: TRANSPORT DISECONOMIES IN SÃO PAULO

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ABSTRACT
This research addresses the issue of sustainability of high-income monofunctional urban structures sprawled within the city, considering as case study Alphaville Barueri residential condominiums in the metropolitan area of São Paulo. The aim was to investigate how these spatial structures are truly sustainable by checking their environmental efficiency according to their mobility behavioural pattern. The methodology used was to calculate the estimated transportation diseconomies produced by these sprawled urban structures through their quantification and establishment of monetary value to three indexes of environmental costs – fuel consumption, air emissions and time in congestion – and then to compare the results of the study case (the Alphaville Barueri residential condominiums) with the results of three control areas (the districts of Morumbi, Alto de Pinheiros and Pacaembu), which have been defined according to their similarity of urban design and socio-economic profile, but with different location taking into consideration the centre of the metropolis. The results pointed out that the Alphaville Barueri residential condominiums are not environmentally efficient in accordance with the defined criteria, when compared to the results of all three control areas, even if one of these areas, Morumbi, showed to be less environmentally efficient than all areas, including the case study.
Keywords: Alphaville, condominiums, environmental efficiency, transportation diseconomies, urban sprawl

1 INTRODUCTION

This research emerged from the observation of the striking multiplication of real estate ventures, high standard residential condominiums, outside the urban areas of major Brazilian cities and in many others. This was widely researched by Moraes [1] in her master's dissertation and largely subsidized the development of this article.

These undertakings announce greater well-being through community life and economic, social and environmental sustainability. Their own developers define it as 'planned, self-sustaining and sustainable poles composed of complete infrastructure for a rational pattern of occupation that guarantees harmony between urbanized space and the environment' [2]. Though this have not shown to be true under the prism of traffic assessments because of their economic dependence on the central business districts (CDB) of the major city they surround and also because of their inhabitant's mobility pattern based almost thoroughly on individual transportation mode (private cars).

As a result of this remoteness from the consolidated urban centres, the sprawling of these high-income residential settlements generates environmental impacts, such as air pollution and congestion, due to the mobility pattern of its occupants.

These impacts, associated with the mobility pattern of the high-income groups of the dispersed settlements, will be evaluated in this article.

From the analysis of urbanistic patterns of low environmental efficiency, this research brings to light the validity of Brazilian current urban policies for the development of cities,

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so that the formulation of new urban policies can include technical parameters for a more socially balanced and less urban fragmented city.

The purpose of this analysis was to question the aforementioned environmental efficiency (in this work understood as a set of indicators of transport diseconomies) of the residential condominiums that constitute these dispersed settlements, given their morphological and functional characteristics that imply in the intensification of commuting displacements, by private cars.

The hypothesis that high-level residential settlements are not environmentally efficient was the main line that guided this investigation. The following criteria was considered: low demographic density, monofunctionality, peripheral location and confinement.

2 METHODOLOGY

This investigation, which is a synthesis of the master's dissertation of the author [1], was based on the study Urban Diseconomy Reduction with the Improvement of Public Transportation [3] prepared by the Institute of Applied Economic Research (IPEA) in cooperation with the Public Transportation National Association (ANTP). At the end of the 1990s, this study developed parameters for estimation of the cost of transport-related urban diseconomies in the case of some Brazilian cities.

The analysis in this article adopted only some of the equations of the desired investigation herein intended in order to estimate the costs of the negative externalities related to individual transportation, configured as the standard mobility of the residential condominiums of Alphaville.

This is largely due to the lack of studies that offer parameters applicable to the Brazilian reality and that allow the estimation of the monetary costs of urban diseconomies related to transportation, and also due to the absence of organized, updated and available planning data.

It is especially important to clarify that the employed method for the research presented in this article cannot be replicated indistinctively to other cities for two major reasons. The first one is the above-mentioned adaptations made for the Brazilian case. The second one is the great distance between socio-economic and urban contexts between the developed countries and Brazil, as Breheny [4] very clearly states in his studies when investigating the London case of effectiveness of the policies and measures created around the compact city concept.

His findings pointed out that the energy savings, coming from the energy consumption in transport, when comparing the dispersed city and the compact-city were, in his words, 'disappointingly low'. Whereas the results obtained in the dissertation [1] that subsidized this article reveal that the high-income urban dispersion in the São Paulo case has a huge financial cost considering the aspects of atmospheric emissions, fuel consumption and congestion time.

Thus, the results of the research [1] suggest that for the application of this methodology to other localities, besides the careful adaptation of the calculation parameters of the indicators studied here for the reality of each locality, and, above all, it should be considered the great economic disparity between cities in developed and developing countries, as in the case of London in England and São Paulo in Brazil, which can have a direct effect on the calculations for the evaluation of environmental efficiency (as defined in the baseline study [1]).

The methodology developed by IPEA and ANTP [3] is basically based on two stages. The first is the quantification of the diseconomies generated by transportation, and the

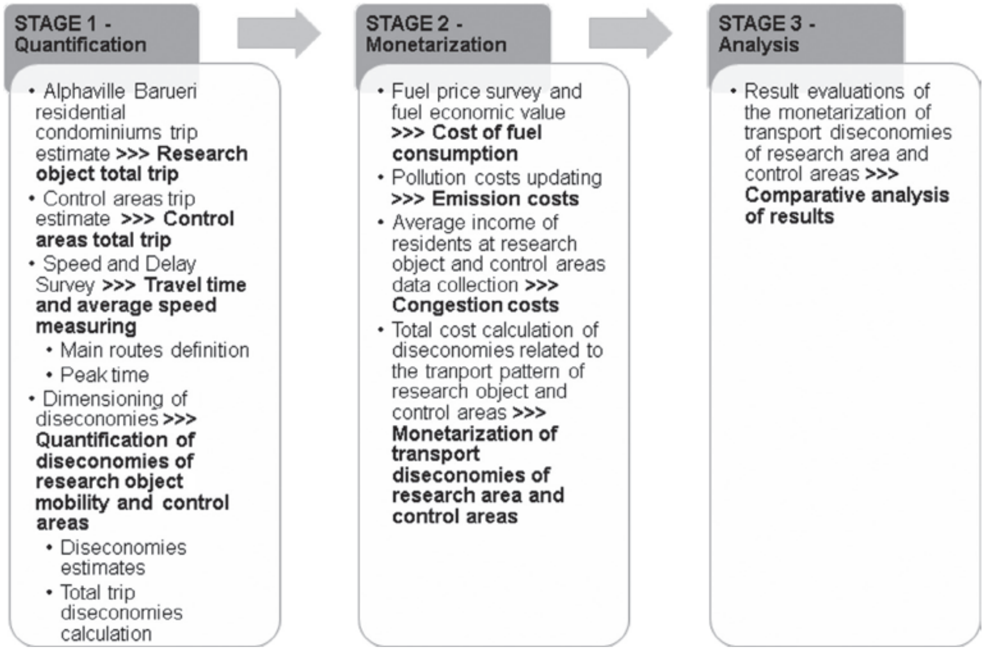

Figure 1: Synthesis of the study methodology.

second is the monetarization of these diseconomies. The aspects considered by this methodology are the time of congestion, fuel consumption and pollution (represented by atmospheric emissions from motor vehicles). Next, Fig. 1 schematically shows the employed methodology.

This research took as a case study the residential condominiums of Alphaville Barueri, in the São Paulo Metropolitan Area (SPMA), comprised by the Zone 425 of the Origin/Destination (OD) Survey [5]. The other three districts in São Paulo city, here called *control areas*, were chosen to constitute a basis for comparison between these areas and the object of study. It was considered the portion of the districts contained by the OD Survey zoning, similarly to the object of study.

Additionally, the control areas met the criteria herein defined as typical of this type of settlements: *low demographic density, monofunctionality, peripheral location and confinement*. Moreover, the socio-economic profiles were considered, resulting in the following chosen districts: Morumbi, Alto de Pinheiros and Pacaembu (Fig. 2).

2.1 Quantification

2.1.1 Estimation of generated travel by research object and control areas

The quantification step starts with the estimation of trips carried out by the target groups of the residential condominiums of Alphaville, as well as in the control areas. The target groups are the residents of Alphaville residential condominiums, high-income individuals, as well as those of the same income class in the control areas.

Figure 2: Alphaville Barueri (Zone 425 of the OD Survey) and control areas (corresponding OD Zones).

2.1.2 Travel time and average speed: speed and delay survey

For measuring the congestion speed and travel times, a Speed and Delay Survey was performed on typical days of August 2014 from each OD Zone studied (which covers the research object and the herein named control areas), in the peak hour of the target groups, on previously established routes, according to the main reason for travel (work), to the centre of the metropolis, even nowadays the place of greater concentration of jobs in SPMA.

2.1.3 Quantification of the indexes of transport related diseconomies

2.1.3.1 Fuel consumption

Fuel consumption, along with atmospheric emissions, is one of the most common indicators related to transport diseconomies, these two indicators are directly related to the speed of the vehicles [3].

The following are the equations [3] used for estimating fuel consumption, eqn (1) per route of each examined area, during morning peak hour (MPH) and the calculation of litres of consumed fuel, eqn (2).

$$C = 0.09543 + \frac{1.26643}{S} - 0.00029S \quad (1)$$

$$L = C^{*}R \quad (2)$$

where:

C = Consumption (L/km)

S = Speed (km/h)

L = Consumed litres per route (L)

R = Route (km)

Table 1: Speed and delay survey results at MPH (9:00 am).

Routes	Route distance (km)	Average fuel consumption (L/km)	Total litres consumed (L)
1. Alphaville – SP Centre	30.0	0.133	3.99
2. Morumbi – SP Centre	12.5	0.207	2.59
3. Alto de Pinheiros – SP Centre	10.5	0.154	1.62
4. Pacaembu – SP Centre	4.5	0.195	0.88

The summary of the fuel consumption estimates and the total of litres consumed in each route analysed, considering the behaviour of the trip at the MPH of the surveyed days, are illustrated in Table 1.

2.1.3.2 Atmospheric emissions

For the adopted methodology, four equations were developed for the quantification of four elements: CO, HC, NO_x and PM (particulate matter). In the case of automobiles, only three equations were developed, considering the most significant pollutants in the emissions of this group of motorized mobile sources. They are CO (eqn 3), HC (eqn 4) and NO_x (eqn 5). These equations are directly related to the speed of mobile sources, like in the case of fuel consumption, but based on speeds ≤ 80 km/h.

$$HC = -2.8 + \frac{62.48}{S} \qquad (3)$$

$$CO = -4.51 + \frac{727}{S} + 1.34 \times 10^{-3} S^2 \qquad (4)$$

$$NO_x = 1.03 + 7.477 \times 10^{-5} S^2 \qquad (5)$$

Where:
HC = Hydrocarbonate emissions (g/km)
CO = Carbon monoxide emissions (g/km)
NO_x = Nitrogen oxide emissions (g/km)
S = Speed (km/h)

The summary of the total emissions of pollutants per route analysed, is shown in Table 2. The emissions of Route 1: Alphaville are significantly higher than the emissions of control areas routes, except for the emission of HC that by a difference of 2.32 g was greater in Route 2: Morumbi.

Table 2: Emissions of pollutants (HC, CO and NO_x) at MPH (9:00 am).

Routes	HC emitted (g)	CO emitted (g)	NO_x emitted (g)
1. Alphaville – SP Centre	66.37	839.57	36.75
2. Morumbi – SP Centre	68.69	792.20	13.35
3. Alto de Pinheiros – SP Centre	31.43	363.79	11.44
4. Pacaembu – SP Centre	22.09	254.37	4.80

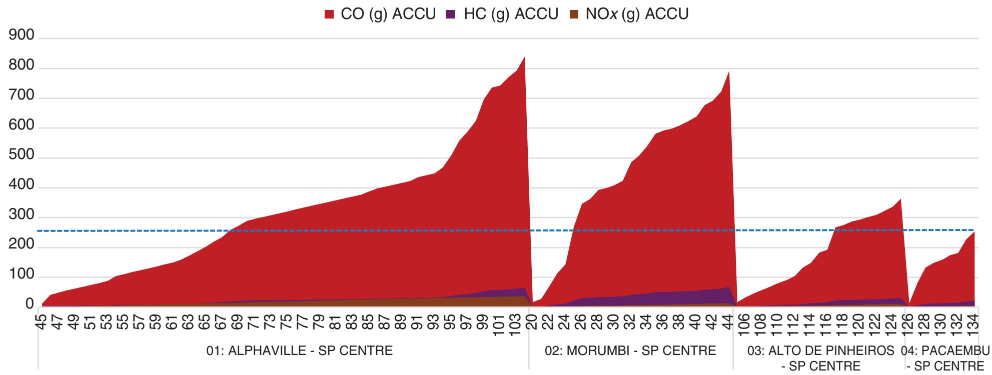

Figure 3: Accumulated emissions (HC, CO and NO_x) by route at MPH (9:00 am).

By comparing the total amount of emissions of each pollutant along each route, it is possible to infer that the distance travelled has a crucial influence in determining the total pollutants emitted along each route (Fig. 3).

It can be inferred that in addition to the low speeds, the length of the routes travelled by motorized mobile sources are also determinant in the final amount of pollutant emissions. Figure 3 above shows the cumulative emissions totals per searched route.

2.1.3.3 Time in congestion

The quantification of the time in congestion does not require an estimation equation, but simply the direct measurement by the carried-out Speed and Delay Survey, that also measured the average speed performed by the vehicle used and the total time in which the vehicle stopped but remained in operation. The results obtained are shown in Table 3, which shows the timing measured in each route.

Observing the data obtained for the time in congestion, it can be noticed that the stopped time of the research object is not the longest one, despite its total travel time being the longest. Morumbi District accumulated the longest time in congestion (stopped time). It is more than twice the time obtained in Route 1, even if its total travel time is almost the same of Route 1.

This situation can alter the perception of the users of individual transport that despite having to go through a longer and slower route, may feel it is worth it due to the relativization of the spent time in traffic.

Table 3: Congestion time at MPH (9:00 am).

	Timing		
Routes	Total travel time	Time in motion	Stopped time
1. Alphaville – SP Centre	1:14:24	1:02:52	0:11:32
2. Morumbi – SP Centre	1:09:24	0:44:12	0:25:12
3. Alto de Pinheiros – SP Centre	0:34:18	0:26:08	0:08:10
4. Pacaembu – SP Centre	0:24:31	0:15:20	0:09:11

2.2 Monetarization

The second stage of the methodology, the monetarization of transport diseconomies, starts from the amounts obtained in the previous stage and calculates the monetary value of these diseconomies, based on the values formulated by IPEA and ANTP [3]. However, at this stage, a correction of the values indicated by the study was performed, given that this study was elaborated in 1998. Table 4 shows the monetary values for each element used in the monetization calculations of transport diseconomies defined by the IPEA and ANTP [3] study and the monetary values corrected by IPC-FIPE Brazilian index. Thus, it is believed to have greater comparative equity and a more realistic approximation of the valuation of measured transport diseconomies.

2.2.1 Cost of fuel consumption

For the total consumption of litres estimated for each route, the cost of this consumption was calculated based on the economic price of gasoline in São Paulo, Brazil, in January 2015, and then this operation was repeated for the volume of trips at peak time for the research object and the control areas, as shown in Table 5.

Thus, it is concluded that the cost of fuel consumption, in this case gasoline, for journeys performed by residential unit in the morning peak hour by the Alphaville Barueri residences are significantly higher than the estimated costs for the neighbourhoods of the control areas. The cost of consumption for the volume of trips in MPH alone is a good indicator of the diseconomy generated by dispersed occupations such as the Alphaville Barueri residences.

Table 4: Monetary correction of estimated values of transportation diseconomies.

Elements of the monetarization calculation	Estimated value IPEA/ANTP [3]	Corrected value (January 2015)
Economic value of fuel (gasoline)	72% Pump price	66% Pump price (66% * R$3.299/L = R$2.177/L)
CO	R$0.19/kg	R$0.45/kg
HC	R$1.14/kg	R$2.74/kg
NO_x	R$1.12/kg	R$2.70/kg
Particles	R$0.91/kg	R$2.19/kg

Table 5: Total cost of fuel consumption for total estimated trips at MPH (9:00 am).

Routes	Consumption, trips and cost			
	Total consumed litres (L)	Cost of consumed fuel by trip (R$/L/km)	Total estimated trips by residential unit (trips/RU)	Total cost of consumed fuel by trip (R$/L/trip)
1. Alphaville – SP Centre	3.99	R$11.08	2,107	R$23,346.04
2. Morumbi – SP Centre	2.59	R$7.19	2,425	R$17,441.64
3. A. Pinheiros – SP Centre	1.62	R$4.50	1,616	R$7,269.96
4. Pacaembu – SP Centre	0.88	R$2.44	2,463	R$6,018.98

2.2.2 Cost of atmospheric emissions

The monetarization method proposed by IPEA and ANTP [3] works with an approximation of the values defined by studies prepared for North America and Europe, which are expressed in US $/kg of emissions. Because of the lack of specific studies that determine some of the specific variables for the Brazilian case, such as dispersion, climate, terrain and health costs related to pollution, the values already estimated by the Americans and Europeans have been adapted by establishing a correlation with the *per capita* income in Brazil and the United States, those values have been updated in accordance with Brazilian economic indexes by the time of this research (January 2015):

$$CO = R\$0.45/kg$$

$$HC = R\$2.74/kg$$

$$NOx = R\$2.70/kg$$

For the estimated atmospheric emission quantities for each route made from the analysed areas at the morning rush hour, we have the results shown in Table 6.

It is noteworthy that, unlike the estimated volumes of atmospheric emissions, Route 2: Morumbi – SP Centre exceeded the costs of Route 1: Alphaville – Barueri in relation to two pollutants: hydrocarbons and carbon monoxide. However, in terms of volume of pollutant, Morumbi had exceeded Alphaville only in terms of the amount of hydrocarbons (HC). These results indicate that the average speed performed and the distance travelled are fundamental to the emission costs of pollutants.

2.2.3 Cost of time in congestion

The study of IPEA and ANTP [3] established an equation for estimating the hour value, which is then used to estimate the cost of time spent in congestion, considering an average income for the whole city, to the detriment of the income of each user of public transportation by bus or individual transportation by private cars. In this study, an approximation was made, adopting the average income within the limits of the OD zone of each analysed area – object of research and control areas – but using the socioeconomic income data of the last census carried out by the IBGE [6], in 2010. Therefore, the equation used to estimate the time value, and then estimate the cost of the congestion time, used in this research was defined as follows (eqn 6):

$$TV = \frac{AIZOD_{\alpha,\, m,\, ap,\, p} \times SC \times FA \times HP}{NH} \tag{6}$$

Table 6: Cost of pollutant emissions (HC, CO and NO_x) for total estimated trips at MPH (9:00 am).

Routes	Cost of HC for the estimated trips (R$)	Cost of CO for the estimated trips (R$)	Cost of NO_x for the estimated trips (R$)
1. Alphaville – SP Centre	R$383.17	R$796.04	R$209.08
2. Morumbi – SP Centre	R$456.41	R$864.49	R$87.42
3. A. Pinheiros – SP Centre	R$139.17	R$264.55	R$49.92
4. Pacaembu – SP Centre	R$149.08	R$281.93	R$31.92

Table 7: Time value and total congestion time at MPH (9:00 am).

Routes	Time value (R$/h)	Time in congestion (stopped time)	Total estimated trips by residential unit (trips/RU)	Total cost of congestion
1) Alphaville – SP Centre	R$33.31	0:11:32	2,107	R$12,866.39
2) Morumbi – SP Centre	R$22.35	0:25:12	2,425	R$22,585.91
3) A. Pinheiros – SP Centre	R$24.29	0:08:10	1,616	R$5,234.19
4) Pacaembu – SP Centre	R$20.05	0:09:11	2,463	R$7,406.02

where:
TV = Time value (R$/h)
AIODZ = Average income in OD Zone (R$/h), being α = Alphaville, m = Morumbi, ap = Alto de Pinheiros and p = Pacaembu
SC = Social charges 95.02% = 1.9502
FA = 0.3 (possibility of alternative use in a useful amount of time)
HP = Percentage of productive use of time (% work trip + % home trip – work * 0.75). When not available, use 0.5
NH = Number of working hours per month = 168 h

By applying the value of the time found for each area of analysis to the time lost in congestion measured in each route and multiplying this result by the number of trips estimated at MPH also for each route, we obtain the total cost of the time in congestion of each route checked, as shown in Table 7.

The cost of congestion among the evaluated routes was high in Route 1: Alphaville even though Route 2: Morumbi reached a congestion cost almost twice that of Route 1. This result indicates that the time stopped in the congestion has significant weight in the determination of this cost. Another factor that points out to be relevant is the fact that all routes, except Route 1: Alphaville, are in urban areas, counting on a road system with low road capacity, with many impedances, while Route 1 is about 80% of its route, highway road system with high road capacity, such as Castello Branco Highway and the Express Way Marginal Tietê, with very low impedances, gaining free-flow speed for longer period of time over the entire course.

3 CONCLUSION: CHALLENGES AND PERSPECTIVES

The results obtained show that the Alphaville Barueri residences came in second in the list of environmental inefficiency under the aspect of mobility, when compared to the Morumbi neighbourhoods, which presented the highest environmental inefficiency. It can be considered that this type of urban structure is not environmentally efficient, for this research, because the rates observed for Alphaville are very close to that of the Morumbi control area (see Table 8), especially regarding to the cost of atmospheric pollutant emissions.

Among the transport related diseconomies herein evaluated, the cost of fuel consumption showed to be the highest among the three of them, and time in congestion the second most expensive diseconomy. This outcome reflects that transport diseconomies related to more tangible issues such as fuel cost and time lost in congestion are more valued financially.

Table 8: Classification of environmental efficiency according to the monetary values of the object of study and control areas.

Areas of analysis	Indicators			Environmental efficiency classification (R$)
	Cost of fuel consumption (R$)	Cost of atmospheric emissions (R$)	Cost of time in congestion (R$)	
Alphaville	23,346.04	1,388.29	12,866.39	37,600.72
Morumbi	17,441.64	1,408.32	22,585.91	41,435.87
A. Pinheiros	7,269.96	453.64	5,234.19	12,957.79
Pacaembu	6,018.98	462.93	7,406.02	13,887.93

Atmospheric emissions have shown to be less relevant transport diseconomy, perhaps because it is a diffuse and less concrete impact. Calculations for their monetarization do not include the costs of their effects on current and future human health. This can be justified because the value of life and the cost of health of every individual in poor and developing countries are not high.

These results reveal how unbalanced the technical parameters regarding the pricing of transport diseconomies are and indicate the urgency of their revision and the establishment of new methodologies for estimating the environmental impacts related to transport and tackle the challenge of incorporating this technical-scientific framework into the design of public policies so that the regulation of urban development is more equitable.

In the Brazilian case, the existence of a large gap in the technical-scientific development regarding methodologies for estimating the diseconomies related to transport must be added, either because of its complexity or because of the unavailability of updated organized planning data.

Despite the imbalance between the transport diseconomies evaluated, the variables that make up each one of the indicators adopted for the evaluation of the environmental efficiency, have shown to be fairly balanced as Table 9 illustrates.

Although with different weights in the composition of each indicator, the variable present in all indicators is the 'total distance travelled'. This variable suggests the importance of the location of urban occupation and brings out the relevance of the inclusion of the urban dispersion debate in public policies and moreover should consider being more restrictive regarding

Table 9: Analysis of the weight of the variables of each indicator.

Indicators	Variables	Weights
Cost of fuel consumption	Total distance travelled	++
	Average speed	+
Cost of atmospheric emissions	Average speed	++
	Total distance travelled	+
Cost of time in congestion	Time in congestion	++
	Total distance travelled	+

territorial occupation and urban production monitoring seeking to reduce the time lost in long daily commuting.

Although the statement of sustainable development is embedded in the rhetoric of public policies at its various scales (local, regional, national and international), in practice, urban development is still largely driven by economic growth. This statement is commonplace regarding theories of unequal and predatory development. However, for genuine change to occur, it is absolutely necessary that the social and environmental dimensions place themselves at the centre of the social structure and the economic dimension lies on the periphery of the first two as a framework of support that enables the desires expressed by that society.

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THE THIRD BOSPHORUS BRIDGE AND THE NORTHERN MARMARA MOTORWAY PROJECT

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ABSTRACT
Build–operate–transfer (BOT) model is extensively used by many governments throughout the world for the realization of large-scale transportation projects. As a rapidly developing economy, Turkey is also increasingly referring to the use of the project finance model for delivering large-scale transport, energy and healthcare projects. Istanbul, located between Asia and Europe, is one of the most important economic centres of the country. Based on this model, rapid urbanization and population growth are taking place in the city. Growing concerns over the insufficiency of the existing two bridges in meeting the traffic demands of cross-continental transport in Istanbul have urged central and local governments to find a solution for the traffic congestion problem. As a result, the government of Turkey has announced plans for building a new bridge to connect the European and Asian sides in early 2011. The construction of the new Bosphorus Strait Crossing Project which has started in 2012 is expected to be completed by 2015. However, since its launch, the project faced many diverse challenges such as delayed tendering, legal disputes, financial problems and social opposition. This study aims at exploring the problems experienced and the solutions developed as a response to these problems in the implementation and management of the third Bosphorus Bridge and the Northern Marmara Motorway Project using a case study approach. To achieve this objective, necessary data regarding the tendering process were collected from various sources. The conclusion provided at the end of this case study is expected to enhance our understanding of the use of BOT model for transport projects and risk allocation between different actors. Both public and private sector participants that are involved in delivering transport projects using the BOT model may benefit from the findings of this study.
Keywords: built–operate–transfer, case study, guarantees, risks, toll roads, transportation projects, Turkey

1 INTRODUCTION

Istanbul is the most populated and economically important city in Turkey, which is located between two continents, Europe and Asia. The city is known by its notable Bosphorus Strait which connects the Black Sea in the north to the southern seas (Marmara, Aegean and finally the Mediterranean) and also Asia to Europe. Thus, the Bosphorus Strait is considered to be world's one of the most important sea and land transport centres.

The oldest idea in building a connection between two continents dates back to the Persian King Darius, who crossed his army from the Strait by a bridge made of boats. Since then, a variety of different ideas were put forward, especially in the last century of the Ottoman Empire (1800s) such as the Hamidian Bridge and several Tunnel projects. However, only in 1973, the first connection between the two continents could be established by the completion of the first Bosphorus Bridge. Later in 1988, the second bridge was constructed in approximately 5 km north of the first bridge. Upon realization of the insufficiency of these two bridges in overcoming the traffic congestion problem, the Marmaray Rail Tube Tunnel Project was also launched (see Gundes and Ergonul [1]) and entered into service in 2013. In addition, the construction work is going on to complete the Avrasya highway tube tunnel which has started to be realized with the build–operate–transfer (BOT) model in 2011.

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The accelerated population growth in the city, which by now amounts to approximately 14 million, consequently caused the physical boundaries to grow outwards. The salient growth in particular towards north and the continuing traffic congestion problem in the two bridges fostered interest in the construction of a third bridge in the northernmost point of the Bosphorus Strait. In 1997, 9 years after the completion of the second bridge, the Ministry of Construction has announced its plans to build a new bridge on Bosphorus Strait. However, studies were accelerated only after 2004 when the current government announced that they were reconsidering its construction. Finally, in 2011, the third bridge and connection highways project was opened to tender using the BOT model. However, a variety of problems became evident from the beginning. Preliminary concerns raised about the project were the controversial location of the bridge and the route of the connection highways as the selected region is characterized by forests recognized as the 'lungs of the city' and watersheds. Concerns surrounding the project were not only limited to environmental issues. As the project started to evolve, several other problems regarding the organizational, financial and risk allocation structure emerged. All these challenges necessitated major alterations to the scope and structuring of the BOT project.

This study explores the organizational, financial, economic, social and environmental challenges experienced in the realization of the third Bosphorus Bridge and the Northern Marmara Motorway Project using a case study approach. According to Proverbs and Gameson [2], the case study research is highly relevant to those industries that are project based and have many different types of organizations. As the use of case studies as a research method provides 'a source of insights and ideas in the early stages of investigating a topic' (Fellows and Liu [3]), and thus expands existing knowledge, it is highly important for future research. The necessary data regarding the tendering process were collected from articles, archives, interviews and briefings of associated institutions in both public and private sector. In this concept, emphasis was given to the use of BOT model and the allocation of risks between private and public sectors. The next section provides a brief overview of the location and technical structuring of the project.

1.1 Background of the project

Today, Istanbul's population has reached 14 million and there are approximately 3 million vehicles. Considering the transit pass through the city, it is estimated that everyday approximately 15 million people travel on roads and highways. Despite efforts to expand railway and sea transport in the city, roads and highways still carry 87% of traffic load. Consequently, while the daily capacity of the existing bridges is 250,000, approximately 600,000 vehicles cross the bridges connecting the two continents. Therefore, the first aim of the project was to tackle the traffic congestion problem and to establish the more secure highway infrastructure in the Marmara region. Accordingly, the project further aims to minimize the economic loss resulting from long travel times in the city and the corresponding high levels of fuel consumption, to reduce emissions and noise, and to enable an interrupted transit freight between the two continents.

After many alterations to the project scope which will further be examined, the final project included the construction of a highway passing through the northern part of Istanbul and of a bridge connecting the two continents between Garipce and Poyrazkoy. In this concept, 60 km of highway (2 × 4 lanes), 35 km of connecting roads (2 × 4 lanes) and a 2,164 m long bridge (2 × 4 motorway and 2 × 1 railway) will be built.

Figure 1: Turkey Planned Highway Network until 2030 (source: KGM [4]).

As shown in Figure 1, the route of the project is designed to be connected to several existing and ongoing motorway and bridge investments. These include connections to the existing Trans-European Motorway and to the ongoing BOT Gebze Izmir Motorway Project involving the Izmit Bay Bridge. Furthermore, the project will also provide a connection to the Tekirdag, Canakkale and Balikesir Motorways. All these investments enable Istanbul to connect to the southern regions of the country.

A high interconnectedness is also planned for the railway system on the bridge and the existing infrastructure investments in the city. In this concept, connections to Marmaray and the current subway lines are expected to link the old Atatürk airport in the European side, Sabiha Gokcen airport in the Asian side and the ongoing third airport. However, perhaps the most important project that the third Bosphorus Bridge and the Northern Marmara Motorway interacts is the ongoing third airport for Istanbul. The BOT airport project will be the largest airport in the world when completed in 2017. Figure 1 shows the location of the new mega airport project and its connection to the Northern Marmara Motorway.

The first tender was opened in 2011. However, no bids were submitted in the first tender as the perceived risks of private investors were very high. The failure in the first tender was a turning point for the scope and risk allocation structure of the project. Therefore, the challenges and the ways of which these problems are dealt with are discussed in detail in the next section. The date of the second tender was 20 April 2012 (Anadolu Ajansı [5]). Tables 1 and 2 show the names and country origins of companies that have purchased tender documents for the first and second bidding of the project. As shown in Tables 1 and 2, while 18 firms including nine foreign firms purchased documents in the first tender, only three foreign and eight Turkish firms have expressed interest in the second tender. Therefore, it can be stated that the interest of foreign firms for the project has significantly decreased after the project scope was narrowed.

Table 1: Companies that have purchased tender documents for the first bidding.

No	Company	Origin
1	Stradag	Germany
2	FCC Construction	Spain
3	Astaldi	Italy
4	Obayashi	Japan
5	Mitsubishi	Japan
6	Itochu	Japan
7	IHI	Japan
8	Moskovskiy Metrostroy	Russia
9	OOO NPO Mostovik	Russia
10	Mapa Construction	Turkey
11	Cengiz Construction	Turkey
12	Park Holding	Turkey
13	Varyap	Turkey
14	Yuksel Construction	Turkey
15	Kolin Construction	Turkey
16	Nurol Construction	Turkey
17	STFA	Turkey
18	Gulsan Construction	Turkey

Table 2: Companies that have purchased tender documents for the second bidding.

No	Company	Origin
1	Astaldi	Italy
2	Salini	Italy
3	POSCO E&C	S. Korea
4	Mapa Construction	Turkey
5	Cengiz Construction	Turkey
6	Park Holding	Turkey
7	STFA	Turkey
8	Guris Construction	Turkey
9	Atli Machine Const.	Turkey
10	Yapi Merkezi	Turkey
11	Alsim Alarko	Turkey

Table 3: Companies that have submitted bids in the second tender.

No	Company	Origin	Status
1	Salini-Gulermak JV	Italy–Turkey	Accepted
2	Ictas-Astaldi JV	Italy–Turkey	Accepted
3	China Communications Construction-Dogus-Yapi Merkezi-Arkon JV	China–Turkey	Rejected (missing document)
4	MAPA Construction	Turkey	Rejected (technical incompetence)
5	Cengiz-Kolin-Limak-Makyol-Kalyon JV	Turkey	Accepted

Table 3 shows the names of the five joint ventures and companies that have submitted bids in the second tender. The application of the joint venture led by China Communications Construction (no. 3) was rejected from the start due to missing documents in the bidding file. The technical competence of bidders was then evaluated using a point scoring system out of a maximum of 100 points. Three joint ventures, namely Salini-Gulermak, Ictas-Astaldi and Cengiz-Kolin-Limak-Makyol-Kalyon, were able to pass the required 70 points in the evaluation of technical competence.

Finally, evaluations were completed and the successful bidder was announced on 29 May 2012. Ictas Insaat Sanayi Ticaret AS-Astaldi JV (ICA) won the tender with a concession period of 10 years, 2 months and 20 days. The construction would be completed in 36 months with a cost of approximately 2.9 billion US dollars. Therefore, the duration of the operation by the JV is approximately 7 years. The second bidder Cengiz-Kolin-Limak-Makyol-Kalyon JV proposed a concession duration of 14 years, 9 months and 19 days which is approximately 40% longer than the winning bid (Anadolu Ajansı [6]).

The due date for the commencement of construction works was fixed in the contract specifications; therefore, the ministry announced that the winning bidder was obliged to start construction works with equity even if the required funds could not be obtained on time from financial institutions (CNN Türk [7]). The construction of works has started in 2012 after the second tender and will be completed in 2015. The concessionaire will operate the bridge and highways for approximately 7 years, and the infrastructure will then be transferred to Turkish government at the end of the concession period.

1.2 Organizational structure

The project company, ICA joint venture, comprises two groups of shareholders including Turkey-based IC Ictas which holds 66.6% of shares, and Italy-based Astaldi which holds the remaining 33.3%. These two groups also have previously formed a joint venture for the realization of the West High Speed Diameter Project in Russia and the new airport of St. Petersburg.

The French structural engineer Dr. Michel Virlogeux and the Swiss T-Engineering have jointly assumed the conceptual design of the project. Belgian Greisch (structural calculations and construction methods), Temelsu International Engineering Services Inc. (Turkey), Swiss

Lombardi Ltd. (evaluating the thermal behaviour of the bridge's tower shafts and approach slabs due to concrete pouring), French CSTB (aerodynamic performance), Dutch Fugro (foundation design) and SETEC (design control) have also contributed to the design of the bridge.

The construction contract for the bridge was awarded to the joint venture comprising South Korea-based Hyundai E&C and SK E&C with shares of 60% and 40%, respectively. The contract that was signed on July 2013 valued 697 million dollars (Construction Week [8]).

1.3 Financial structure

Total project cost is approximately 2.9 billion US dollars. Debt to equity ratio is 80/20. Six local banks, namely Garanti Bankasi, AS (366 million US dollars), Halk Bankasi AS, İs Bankasi AS, Vakiflar Bankasi TAO, Ziraat Bankasi AS and Yapi ve Kredi Bankası AS (386 million US dollars each), and one Netherlands based bank Garantibank International NV (20 million US dollars) agreed to underwrite the 2.3 billion loan. The loans provided by banks have a maturity of 9 years and 5 months. Therefore, the repayment is planned to be completed on 5 March 2023.

The remaining 600 million US dollars is provided as equity by the two shareholders in the project company. According to contract specifications, the project company is obliged to start construction works in 6 months after signing of the contract. However, ICA JV has started construction in September 2012, before the due date, using 581 million US dollars of equity. In accordance with the respective shares of 66.6% and 33.3% of the two companies in the joint venture, 387.33 million US dollars of the equity is provided by IC Ictas and the remaining 193.67 million US dollars is provided by Astaldi.

A notable feature of financial agreements was the small amount of foreign funding despite the wide range of government guarantees and special rights provided to the project. Indeed, the use of local capital markets in financing private toll road projects is a preferred option for many projects worldwide. Fishbein and Barbar [9] provide several reasons for the recourse to local finance in toll road projects. First, foreign exchange risks can be mitigated by the use of local capital as the currency of toll revenues generated by the project and the debt service will be the same. Second, financial negotiations will be easier as local financial institutions with a better understanding of the local context are more willing to assume economic and political risks. Third, raw materials and other inputs required in the construction of toll road projects can generally be provided locally. Therefore, there is no need to fund construction costs in a foreign currency.

Although the majority of banks in the third bridge and Northern Marmara Motorway Project were local, the loans were obtained in foreign currency. Foreign exchange risks were mitigated through toll payments based in the same currency [e.g. bridge: 3 US dollars + VAT (cars), 15 US dollars + VAT (heavy vehicles); highways: 0.08 dollars/km]. Therefore, limited ability to attract foreign capital cannot be attributed to foreign exchange risks but to other problems and risks surrounding the project. These are examined in the next section with explanations about the way in which and how the problems are dealt with in our BOT toll road representative case. In this concept, key lessons learned regarding the application of the BOT model for transportation infrastructure are also emphasized.

2 CHALLENGES ENCOUNTERED AND PROPOSED SOLUTIONS

In addition to the social and environmental concerns surrounding the project, the tendering process of the new bridge also received heavy criticism from opponents. The first bidding process for the BOT project had to be cancelled as no bids were submitted due to financing problems. Thus, the project could only be put to tender again after some important modifications were made to the project and to existing specifications including government guarantees, the scope and several legal arrangements. The remaining part of this section addresses the challenges encountered in the tendering process by examining the differences between two tenders in detail. In this concept, risk allocation between parties and guarantees provided by the public sector will be emphasized in order to clarify how the aforementioned modifications could enable the feasibility of the project for investors.

2.1 Project scope

As a response to the failure in the first tender, the government displayed determination to realize the project by stating that other procurement models such as the traditional and international agreements could also be considered in case there will be no demand for the BOT model. Indeed, this statement showed the commitment of the government and the importance attached to the realization of the third bridge project.

First considerations regarded reductions in the scale. The project in the initial tender contained several different major parts that could be considered as subprojects such as highways, a bridge and connection roads. Accordingly, the capital investment in the first tender amounted to approximately 6 billion US dollars. Thus, it is not unexceptional that problems in the provision of finance are encountered as the resulting financial costs were very high. Press statements after the failure in the first tender signalled revisions in the scope and specifications of the project. The first move was to divide the project into two separate subprojects that will be tendered separately in order to reduce the total cost. As stated earlier, 299 km of highways, 115 km of connection roads and the bridge were altogether put to first tender. However, in the second tender, the Ministry announced that the bridge, 60 km of highways and 35 km of connection roads would again be realized by the BOT model. The remaining highways and connection roads, on the other hand, would be realized through traditional procurement system. In this way, the project cost was reduced from an estimated 6 to 2.9 billion. US dollars (Habertürk [10]). Moreover, this new reduction in the scope would also reduce the construction time from an estimated 5 years and 10 months to 3 years.

2.2 Market demand (revenue) risks

A major difference between the two tenders concerns revenue risks assumed by investors. The investors attributed the lack of bids in the first tender to the difficulty in obtaining finance for the project due to the insufficiency of government guarantees provided (e.g. see Hürriyet [11], Reuters [12]). Minimum traffic volume guarantees provided by the public sector were perceived to be insufficient and the allocation of risks between the public and the private sector was problematic.

Early statements by the General Directorate for Highways showed that traffic forecasts were considered to be sufficient to make the project feasible as the existing two bridges worked with overcapacity and the surplus capacity in these bridges could be directed to the new bridge (Sabah [13]). However, opponents still claimed that the new bridge was far away from settlements and thus questioned the attractiveness of the new bridge for citizens. In this respect even the State Planning Organization advocated that traffic forecasts were over-optimistic. Although the canalization of the heavy vehicles to the third bridge was considered, the decision was not statutory.

Consequently, several important modifications were made in the minimum traffic guarantees provided by the public sector. In the first tender, the government had agreed to support the project by a minimum traffic guarantee of 100,000 vehicles, whereas the volume was increased to 135,000 vehicles in the second tender. However, unlike other toll road project examples from the world, no ceiling level of traffic demand has been determined.

The assumption of revenue risks by the public sector was one of the most important moves to make the project feasible for investors. The reason for this is the importance attached to traffic demand or revenue risks in the success of BOT-type toll road projects. Previous experience shows that there is a close relationship between shortness of demand and project failures. For example, many BOT projects in Mexico, Hungary and Thailand have failed due to unrealistic assumptions about future traffic demands and the inappropriate revenue risk allocation between the public sector and the private sector (Ashuri et al. [14]). The level of predictability of future traffic demand is the main determinant for setting an appropriate revenue risk allocation structure between the public and the private sector. A project company can generate revenues from a toll road either in the form of direct toll payments from end users or through indirect payments by the contracting authority based on usage. High predictability of traffic level increases the attractiveness of projects for financiers as it will be easier to identify whether toll revenues that will be generated from the project will be sufficient to cover debt service. While the market demand can easily be predicted for improvements to existing roads, traffic forecast become more uncertain in new roads such as the Northern Marmara Motorway Project. Generally, the usage risk is transferred to the private sector in case the expected traffic levels can easily be predicted. In the latter case, however, usually the public sector retains market demand risks through minimum traffic or revenue guarantees.

Increasing minimum traffic guarantees were not the only public sector support that had a positive impact on revenues of the Northern Marmara Project. Another important move to make the project feasible for investors was the announcement of a law about exemption from VAT for BOT projects. New regulation on VAT arrangements allowed a further 18% advantage in the costs of investors and increased the attractiveness of the project.

2.3 Expropriation

Another notable difference between the two tenders regards the level of expropriation risks assumed by the private sector. When the call for the first tender was announced, the date was postponed several times mainly due to demands from prospective bidders. In this respect, one of the concerns raised was about the high amount of expropriation costs that would be assumed by the private sector [approximately 950 million Turkish Lira (TL) over a total of 1.6 billion TL]. As a result, the expropriation costs that will be assumed by private investors were gradually reduced from 950 million TL to 700 million TL and finally to 400 million TL (1 TL = 1.81 $ in 2012). Despite new demands from investors to further suspend the date, the General Directorate for Highways announced that the bidding date for the first tender could not further be postponed. However, the reduction in expropriation costs was not sufficient to increase private interest in the project and consequently no bids were submitted to the first tender, where 18 different groups of investors had purchased tender documents. As a result, the public authority agreed to assume all the costs associated with expropriation in the second tender. In this concept, the government stated that approximately 85% of the property in the route belonged to the public sector and thus the expropriation costs would not be very high (CNN Türk [7]).

2.4 Environmental impacts and social opposition

In the beginning, the project was exempted from performing an Environmental Impact Assessment (EIA) report through a modification made in the EIA Ordinance. Undoubtedly, this further complicated the financing process as many financial institutions have strict policies on maximizing positive development impacts and thus do not provide finance for projects that have negative environmental or social impacts. However, it should also be noted that although the project was exempt from performing an EIA report, later the ministry have announced that an EIA report had been prepared as this is a prerequisite in the provision of funds in particular for foreign financial institutions.

The most striking social oppositions to the Northern Marmara Motorway were shown to the route of the project. An important issue regarding project scope is the altering of the route after the tendering process due to the cancellation of the master plan. In July 2013, many national newspapers reported the cancellation of 1/5,000 master and 1/1,000 implementary development plans (KGM [15]). Several reasons were put forward for this change. First, opponents claimed that the location and the route selected for the project were incorrect as they passed through Belgrade and Fatih Forests. Others claimed that the change in the route was required due to the manifestation of high expropriation costs in the previous route. As a response, ministry authorities decided to continue the route to more northern regions in order to minimize harm to forests. Another alteration was also made on the Asian side of the motorway route in an attempt to protect Polonezkoy National Park (Dünya [16]). However, despite the modifications, opponents further asserted that ‘induced demand’ would be created by the construction of new highways. Arguments centred on the vicious cycle that the construction of new highways would generate new traffic and hence create more demand for yet more roads. The environmental concerns were soon brought to trial. However, the lawsuits against the project opened by professional chambers and non-governmental organizations were not concluded at the time of tender. Therefore, it can be observed that the project was extremely risky for financial institutions that did not want to take the risk of cancellation.

The alterations made to the project signal weakness in the feasibility phase of the project. The feasibility phase of these kinds of mega projects is extremely important. Detailed studies on alternative routes should involve a closer examination and comparative analysis of expropriation costs. The results from this analysis should then be combined with economic, social and environmental impact reports in order to take a decision.

2.5 Other forms of public guarantees

Finally, it is also important to mention that several other forms of credit guarantees are provided by the Turkish government after the project has been awarded to the ICA JV. One of the significant attempts was the provision of treasury guarantees for the project in 2014. According to the new legislation, only the debt provided by international banks will be assumed by 85% of the outstanding debt in case of an early termination of the contract as a consequence of project company default. In other forms of termination such as voluntary termination and force majeure events, the debt assumption commitment covers 100% of outstanding debt.

3 CONCLUSION

This study intensively tried to focus on the application of the BOT toll road model in practice. Although the findings cannot be generalized, the lessons learned offer relevant insights for both private and public sector providers of transportation projects in Turkey and in other developing countries.

Several conclusions can be drawn from the way in which the challenges are dealt with in the realization of the third bridge and Northern Marmara Motorway Project. First, political support in each stage is extremely important. Without the project-specific support provided by the government, the case study project would not be accomplished due to financial problems. Second, a clear risk assumption structure by the appropriate partner is imperative for economic viability. Revenue risks in BOT toll road projects are of particular importance. In this regard, the predictability of future traffic volume should be the main determinant of risk allocation between private and public sectors. Third, strong political support and the assumption of revenue risks by the public sector may not be sufficient to increase the attractiveness of projects for financial institutions. The case study has shown that despite the strong government support, negative public perception and in particular environmental concerns complicate the financing process. Treasury credit guarantees provided after the tender prove that environmental problems and social oppositions which lead to lawsuits are perceived to be a very important risk factor for financial institutions. The case study once again has demonstrated the strength of interactions between financial and environmental viabilities of projects. Therefore, above all, a comprehensive and integrated assessment of environmental, technical and economic aspects in the feasibility phase and a clear legal structure to base these evaluations are crucial for success not only in BOT toll road projects.

Consequently, these findings address to structural problems independent from the scope of the case study. Developing countries' lack of political and economic stability, proper regulations and environmental policy are a candidate to encounter identical issues in various kinds of BOT projects (e.g. airports, toll roads, bridges, power plants, etc.). Temporary and political endeavours to solve problems faced off in the context of single project do not work well in long-term outcomes.

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TOWARDS SUSTAINABLE URBAN LOGISTICS: THE EVOLUTION OF DIGITAL MARKETPLACE

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ABSTRACT

Many existing industrial solutions for transportation services assume tightly controlled optimization scenarios where the price does not take a centre role, yet these models heavily rely on long-term business relationships between shippers and carriers. A number of solutions have been proposed for auction-based marketplaces with market-clearing property models, where supply and demand dictate the price and through innovation and improve transparency and efficiency. The overall objectives of these efforts are aimed at finding a balance that assures maximizing capital efficiency, maximizing customer satisfaction and minimizing logistical complexity, hence maximizing scalability. Some Uber-like experiences have recently emerged, introducing fresh perspectives and putting back the spotlight on the potential of digital markets in transportation industry.

In this article, we take a look at how the ideas of digital marketplaces have evolved over time and specifically consider how the lessons learned can be applied in last-mile urban logistics. We also present a prototype marketplace for urban city logistics and draw initial conclusions.

Keywords: auctions in freight, digital marketplace, last-mile urban logistics, multi-attribute auctions

1 INTRODUCTION

Even in an industry like trucking which is quite resistant to innovation and modernization, the latest era of easily available and always connected GPS-enabled smartphones is reshaping existing ideas and transport practices. By leveraging truck drivers' smartphones easier, faster and more direct iteration is enabled between the drivers and nearby companies in need of shipping services. This market liberalization assumes skipping classical brokers and uses an online service acting as a digital broker: this solution gives autonomy also to small trucking firms and independent truckers, while enabling shorter response time, more efficient routes to pick up and delivery and a better payload.

The idea of transportation marketplaces is not new, but the rise of Internet sites and the tech industry 15 years ago had brought a number of start-ups, attempting to modernize the way shippers and carriers worked together. They failed mainly due to the lack of understanding of how the market worked, empowering the shipper and discouraging the carriers with the goal simply driving down the cost for the shipper.

The difference is that this time around the new solutions are built not aside but around basic concept of transportation being a relationship-based business. Indeed, trusted relationships are crucial as they also impact customer service and satisfaction which translates to shipper's brand and reputation. It is why the vast majority of freight is still being transported by contracted carriers and does not use the spot market. This is the reason why the newest solutions [1] don't exclude having 'preferred carriers' in order to solve the inefficiency and division of the local trucking industry in urban last-mile logistics. This time around the emphasis is on having a balanced added value proposition for both shippers and carriers. As opposed to previous solutions that mainly benefited the shipper by driving the price down, the focus is on connecting shippers and carriers directly and efficiently by avoiding external brokers, and giving the carriers tools to maximize asset utilization and efficiency leading to lower costs

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for shippers. Actually, new innovative solutions merge the e-commerce ideas with traditional freight brokerage model based on relationships, and also offer new interaction technologies through continuous vehicle connectivity and advanced analytics on carrier data allowing fully dynamic scheduling.

In this article, we first look at the overall urban city logistics, then at the evolution of digital marketplaces in the transportation industry and lastly focus on how urban logistics, still driven by traditional freight brokerage model, are facing with modern requirement for sustainability and reduction in pollution. In the following section, we present a use case of the city of Milan (Italy), which was analysed in the scope of Italian national project OPTILOG (OPTImal and sustainable LOGistics in urban areas). The project's objective is to promote and test innovative solutions for planning and management of last-mile logistics, enabling efficient and sustainable last-mile transportation service. We describe the developed platform for urban logistics in large cities, prototyping a digital broker for connecting shippers (i.e. extra-urban operators) whose vehicles don't have access to historical city centres to last-mile delivery units that satisfy city regulations for lower gas emission (i.e. bicycles, electric vehicles, etc.). We present a marketplace auction model that assigns loads to last-mile operators taking into account their characteristics and relying not only on the price of the shipment.

2 CITY LOGISTICS AND DIGITAL MARKETPLACES

Munuzuri et al. [2] identify a series of commonalities for European cities that influence their mobility and commercial activities as well as impose a series of restrictions related to the flow of freight deliveries. Freight transport has been perceived as nuisance and its issues are frequently ignored by governments (too slow and polluting vehicles). However, urban delivery needs are a necessity, and lately a number of cities have been promoting city logistic measures along with sustainability issues [3, 4]. While measures around environmental performance of vehicles are based on promoting usage of less polluting, governance measures are frequently implemented through limited traffic zone (LTZ) areas with time-window access for different types of transportation vehicles or night-time delivery options.

The introduction of multiple actors perspective is of interest to us as it allows characterization of urban freight system by multiple stakeholders with conflicting objectives. And when no centralized authority is present, as mentioned in Ref. [5], all stakeholders act autonomously, basically making urban freight transport into a distributed decision-making system where different carrier-agents negotiate through an auctioning mechanism for logistic contracts.

Over the last decade, a large emphasis on advances in transportation industry has been put on collaboration efforts of shipper–shipper [6], carrier–carrier [7, 8] and shipper–carrier [9] types. The main reason is the significant amount of empty trips leading to additional costs and higher rates for carriers, hence the constant struggle to maintain profitability. While, on the one hand, advances in Internet technologies have created new challenges and demand for meeting on-time delivery and pick-up expectations, they have also created new opportunities for increased coverage, and carrier–carrier collaboration across similar types of carriers. Peeta and Hernandez [9] have analysed a number of marketplaces for freight transportation service procurement, focusing on different operational modules used in existing marketplaces and on two types of contracts: short-term contracts (spot market) and long-term (binding) contracts. A major advantage of online marketplaces over traditional solutions is in lowering transactional costs as there is no need for extra personnel for timely transactional or contractual negotiations with each individual carrier. This leads to lowering freight bills and easier filling of carrier's excess capacity.

Electronic marketplaces can be broadly classified as clearing houses (bulletin boards), auction houses and freight exchange. In the clearing house scenario, both shippers and carriers post their requirements, and information stored in a database of loads posted by shippers and transportation capacity posted by carriers is used to initiate one-to-one negotiations. Transportation auctions assume auctioning of either long-term contracts in a large-scale combinatorial auction settings or auctioning of transportation capacity in a spot market. Finally, in an exchange, shippers and carriers exchange demands for transportation service for assurance to provide transportation capacity, where the matchmaking at competitive price is done by the online marketplace. Having said this, a number of doubts have reason over the years including the fact that 'public' marketplaces themselves do not assume responsibility for actual movement of freight (i.e. monitoring execution and performance of other businesses) but rather just focus on matching demand and offer. The marketplaces can be either public or private, where an important feature is to guarantee reliability of the marketplace by assuring all shippers and carriers have been certified based on their service records and business credentials.

In the last years, major logistic software providers, logistic provider companies, less-than-truckload (LTL) and truckload (TL) trucking services opened their own marketplaces, which due to the above-mentioned doubts (i.e. responsibility for execution of service, fear of cutting into already low margins for carriers, etc.) shut down or consolidated forming strategic alliances. A major factor in their demise was not considering that many shippers and carriers still put high value on traditional trust built through common experience and years of person-to-person negotiations. Hence, it is up to the marketplace to take the regulatory role or devise a business model based on customer feedback, to assure and provide reliable information regarding the agents that use the marketplaces in order to convince all participants and attain the necessary customer base to make the marketplace viable.

3 DIGITAL MARKETPLACES AND AUCTIONS IN FREIGHT

Online procurement auctions are frequently used to dynamically match demands and offers, enabling efficient ways to allocate resources like capacity. In classical freight transportation setting, online procurement auctions are mostly used by shippers who could not manage to place a shipment with preferred carriers due to time-window constraints, capacity issues and/or low-profitability reasons. Hence, in the initial stage, freight industry auctions became a useful mechanism for both shippers and carriers to reallocate problematic shipments to other carriers that might have resources to do it.

An auction is characterized by bidding rules, market clearing rules and information relevant policies. Well-known types of open auctions include English auction and Dutch auction [10], while closed-price auctions include first-price and second-price auctions. Alternatively, combinatorial auctions deal with multiple items put out for bidding where bidders can bid on combinations of these items. These, in the transportation industry [11], are used for procurement of long-term contracts for serving packages of lanes [8, 12–17]. In case of transportation industry and an online marketplace negotiation scenario the items put out to bid are lanes or loads with specified demands. The information flow between shippers and carriers during an auction assumes that each carrier can make a bid, and shipper chooses the best bid after which the carrier can decide to make a new bid. The auction itself can be an intermediate actor, agent, or web portal. Carriers need to decide on what loads to bid on and what price to charge for a load; in order to achieve this, they need to calculate the marginal utility for the load, and this is referred to as the bidders' problem. On the other hand, the shippers consider not only the price of the transportation service proposed by a carrier but also other attributes like service characteristics and good business relationships to select winners; this is referred to as the shipper's winner determination problem (WDP). In case of electronic marketplaces, the pricing approach even though frequently automated must stay competitive and needs to simulate off-line market conditions, it must be fair and take into consideration different service packages, seasonality, volatility of demand and supply, business rules and present restrictions. An auctioning mechanism that corresponds to this type of applications is the reverse-type auction as described in Ref. [18]; the sellers (i.e. carriers) compete to obtain business from the buyer (i.e. shipper) and prices will typically decrease as the sellers underbid each other. From the above literature review, we can note that combinatorial auctions for transportation services have been researched in detail and applied in a number of commercial software tools specifically in cases of auctioning long-term transportation contracts. However, in case of sport markets that correspond to city logistics, the economic mechanisms for offering discount spot transportation prices give rise to other types of auctions that are less complex.

3.1 Multi-attribute auctions in freight transport

van Duin et al. [5] modelled the modern state of freight logistic business strained under strong pressure to respond to specific demand for delivery of goods and services, including customized product deliveries, late modification of product specification, late orders and volume changes all requiring adaptation while still requesting strict delivery times. In order to deal with this uncertainty in demand the carriers are obliged to account for potentially extra capacity and time in trip planning. This leads to overbooking which increases costs, hence carriers attempt to minimize costs and optimize their trips. The model assumes that the part of the service is assured through planned delivery tours based on contracts with numerous carriers for a fixed-based volume of freight. And another part that corresponds to additional non-contracted shipments is handled through auctions with several interested carriers in a sport market scenario, where the carrier with best cost, capacity and service quality wins the bid. The auction used is a multi-attribute, that is multi-dimensional auctions where the buyers' requested orders are described through a number of attributes that can be any combination of monetary and non-monetary units. Ma et al. [19] and Wang et al. [16, 20] modelled the WDP for TL procurement in combinatorial auctions, where important business sides constrain and considerations are included in the model.

Similarly, multi-attribute vectors can be used for describing the bidding items that have non-price attributes as required service quality and time windows of delivery. Potential factors that influence a carrier's demand price can be profit, the number of loads he/she has already won, his/her expectation for gain in the geographic area and so on. Carriers can apply specific discounts that model their behaviour in desire to obtain a fully planned schedule as soon as possible. In this scenario, carriers who have not secured income for the time period in question might be more willing to lower prices even if this leaded to for some percentage lowering their potential profit. The willingness to lower profit might also increase as rounds of the auction progress. Typically, in case of carriers in order to form a bid price several factors must be taken into consideration including costs as the distance to be driven, travel time related to the cost of a driver, estimated costs related to the use of vehicle and so on. In order to form a bid price, the carriers can use various optimization approaches to estimate their cost as versions of vehicle routing problem (VRP).

In this article, we mention VRP in the scope of transportation auctions as it is one of the tools that can be used by carriers to define/generate the price for their bids. The details of these types of approaches are out of the scope of this article; however, for the sake of completeness we note that the OPTILOG project also implements a classical VRP-TW (a VRP with time windows) with constraints [20]. The original idea behind the usage of VRP approaches is to define the optimal route by minimizing the total cost for carriers, and might work well when the carrier can impose the optimization and monitoring on its vehicles (drivers). However frequently the last-mile carriers in city logistics are associations of independent carriers under contract and imposing a specific way, limitations in the delivery itinerary in terms of delivery times or delivery sequence might present a major obstacle. The carriers are under contract and their profit depends on the number of deliveries, kilometres passed, the delivered weight and so on. Hence, they might be willing to accept recommendations but concerns have been raised that they might react negatively to strict monitoring as it is seen as an instrument of control. Therefore, in our implementation we also offer a less strict solution with distance-based clustering that can be used within our action-based marketplace.

3.2 Marketplace for city last-mile logistics

In an urban city scenario with daily outsourcing of delivery orders (DOs) to carrier companies for transporting [20–23], a multi-actor auctioning system can be used for allocation of orders through bidding in a group of companies accredited with the auctioning system of the logistic company. In fact, it is not unusual that the company that accepts the transportation order doesn't own transportation capacity (i.e. the considered case of city of Milan), actually often large companies prefer to outsource the delivery to logistic companies that further negotiate the distribution of orders with smaller companies with transportation capacity. This generic setting of the OPTILOG project platform corresponds to the modern logistic tendencies where the focus is on city logistics, that is the second part of the market interaction once large TL carriers have brought the merchandise to the city and last-mile logistics step in. As an example, the model described in Ref. [16] is a two-tier solution with two layers of terminals (i.e. ULD (Unit Load Device)). One on city borderlines where national trucks arrive and merchandise is consolidated/deconsolidated onto smaller trucks and further delivered to second later terminal where it can be consolidated/deconsolidated onto sustainable vehicles (e.g. electric vehicles, cargo bikes, etc.) and delivered to destination (i.e. destination itself or parking bays where last metres of delivery are made on foot) in city centre that has specific regulations (e.g. ZTL (Limited Traffic Zone) zone, Area C). Schwind et al. [15] modelled the exchange of cargo capacity in a city through an online logistic marketplace, a combinatorial auction and inner-city terminals that all belong to the same company (i.e. intra-enterprise setting). Their overall scope is on reducing the total cost of transportation of the logistics company, owning all the terminals and carrier vehicles, through reduction of direct delivery costs. In an extension, Gujo [23] considers a multi-attribute inter-enterprise solution, hence a multi-actor perspective, where the main objective is not only reduction of delivery costs but also meeting customer preferences, thus maintaining customer loyalty and holding market position.

Similarly, in OPTILOG's city logistics setting we consider several UDCs that have individual set of customers already assigned to them based on the destination post codes. This corresponds to the realistic situation where national TL carriers are directed towards specific extra-urban hubs the night before and the information about the merchandise that arrives in the morning is well known to each hub. The merchandise is further directed to particular parts of the city based on postal codes of DOs. The introduction of UDC units enables last-mile delivery through usage of cargo bikes and sustainable vehicles that reduce pollution in congested city centres.

3.3 Current setting for our use case (city of Milan)

Overall in today's city logistics, including the city of Milan, a large portion of freight carrier services in the city is provided by LTL carriers having fixed long-term negotiated contracts with either shippers or logistic provider companies delivering merchandise with their TL fleet to large terminals outside of city lines (e.g. GLS express couriers for the case of Milan). Smaller vehicles of LTL type and specifically sustainable solutions as electric, compressed natural gas, liquefied petroleum gas, hybrid propulsion or cargo bikes are encouraged with a number of sustainable city logistic initiatives, including limited mobility for vehicles not satisfying low pollution standards in the city centres (i.e. LTZ, Area C in Milan). As new regulations and limitations for limiting pollution and traffic congestion are introduced across Europe and Italy the freight industry needs to adapt, hence, even in case of express couriers, a two-tier approach is considered where in addition to large terminals on city borderlines used for received consolidation/deconsolidation of merchandise from large TL carriers, a second level of smaller 'warehouses' (i.e. UDCs) is introduced for consolidation/deconsolidation of merchandise of medium size trucks and sustainable vehicles that are allowed access to LTZ. Additionally, loading/unloading bays close to final destinations are present to deal with parking issues.

In case of Milan and for the two-solicited major express couriers we have similar situation being implemented or in implementation. In case of the first express carrier, we have several out of city warehouses and a number of corresponding UDCs, where the last-mile fleet is around 100 vehicles of small dimensions for the transport of small to medium packages (less than 100 kg) with daily management of delivery in two rounds. In case of the second major express carrier we have again out of city warehouses and UDCs in the city serviced with low polluting vehicles as a dozen electrical vehicles, cargo bikes, several small boxed trucks and so on. Hence, for our development settings three different types of packages were considered for delivery (envelopes, boxes, and fridge-size packages) with several types of vehicles available for delivery within the urban city centre: cargo bikes, vans and small trucks. Different vehicles differ not only by dimension but also by the type of merchandise that can transport, specifically cargo bikes can only transport envelopes, small tracks only fridge-size packages, while vans can transport all three types of merchandise. The carriers have set up their systems this way to improve efficiency.

4 SYSTEM ARCHITECTURE

Before we proceed to describing our system architecture it is important to note that with this work our goal was to demonstrate the feasibility of applying an auctioning system in a day-to-day city logistic activities, and not to prove that any particular bidding strategy or scheduling method is better than others. Rather than that our objective is to model and improve current business practices in last-mile city logistics with automated strategies. As in any auction, the final price will be determined by the bidding in the open market. The overall ideas of this approach are not directly to optimize the planning but on automating the market interactions in a multi-actor logistics negotiation.

In Fig. 1, the overall process of delivery is simulated. Once a client makes a DO consisting of one or more packages to be delivered to a certain address, the order is received by the system and stored in its database. Once majority of DOs for the day are received and stored (i.e. there is a cut-off time usually; major express carriers, having a role of a shipper in our settings, iterate twice per day), a VRP algorithm is run or alternatively a distance-based clustering approach for the scenario of third-party carriers. This leads to a creation of a delivery schedule (DS) that is again stored in the database. For each available DS in the database, the 'reserve' price is calculated by the digital marketplace based on estimates of fair market value. In our setting, the 'reserve' price depends on the fair market value and hence it is not hidden. This step is meant to help out both the shipper and the end carriers participating in the auction. Once the DS is put on auction, several iterations are taken by the system to make a decision. By clearing the auction, the DS is allocated to the winning carrier.

Regarding the system architecture our platform is a client–server system, where the server component OPTI-server manages in obtaining DOs, creation of clusters of DOs to obtain DS and all auction-related activities. The client applications include (i) generator of DOs, a component that simulates clients who need to ship merchandise thereby creating DOs or allows loading on historical data, and (ii) OPTI-client carrier, a component that simulates the behaviour of bidders in an auction. In our case, the carriers are last-mile logistic companies that can participate in an auction, make bids and win it. The OPTI-server component has four modules that manage, receive DOs, cluster DOs into DSs, calculate 'reserve' price for every DS and run the auction. The communication between various client-server software components is through TCP/IP sockets. We present the various components trying to follow the order of execution in a real environment.

The generator of DOs has a task to generate DOs made out of one or more packages and to send them to the marketplace, that is OPTI-server so that they can be processed by the auction system, that is OPTI-engine. Overall our component is designed to be used in both simulation and pilot running settings. That is, the generator of DOs analyses historical data

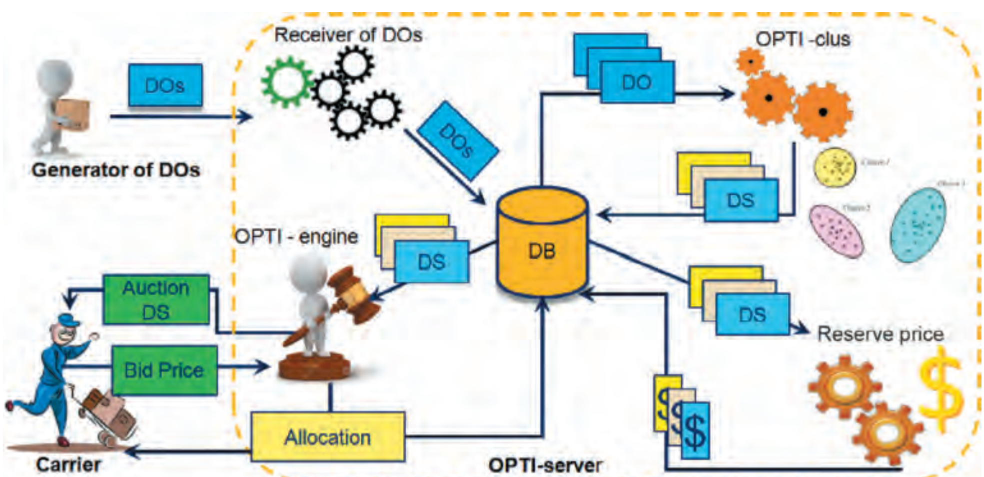

Figure 1: Work flow and system architecture.

to obtain distribution of relevant attributes as: the number of packages, the type of packages (i.e. envelope, box or fridge-size package), relative dimensions (i.e. length, width, depth and weight), coordinates of the order (i.e. latitude and longitude) and anticipated time and day for the delivery. The mentioned distributions are later on used to produce larger amounts of data for simulation purposes. On the other hand, the component can also load historical data from shippers (e.g. express carriers) and runs simulation using real data.

While the receiver of DOs has a task of saving in the database every DO with information about every accompanying package that was sent by generator of DOs through TCP/IP, it also maps geographical coordinates from DOs to a bi-dimensional spatial grid (i.e. for the city of Milan the cells have dimensions of 100 m × 100 m). This information is further used by OPTI-clus module for clustering DOs based on the following constraints: spatial, temporal and type of merchandise. With spatial constraints the goal is to merge several DOs that are 'close' in space. For instance, the system offers an interface with optional parameters to define the number of adjacent cells on horizontal and vertical axes, in this way generating the division of the city area into non-overlapping regions and with it merging of appropriate DOs. Regarding temporal constraints and how they influence the clustering stage of DOs, it has been assumed, based on current practices, that the delivery periods can be selected (i.e. start day and hour, end day and hour), for example: start period 1 November 2016 08:00:00 and end period 1 November 2016 18:00:00. Also these periods can be further divided into non-overlapping time windows for more specific customer delivery (e.g. 2 h, 4 h, etc.). And regarding the last constraint, in the OPTILOG project we consider three types of merchandise (i.e. envelopes, box and fridge-size packages) and three types of transportation vehicles (i.e. cargo bikes, vans and small trucks) which based on their characteristics are suitable for some of the types of merchandise. As mentioned, while vans can transport all types of merchandise, bicycles can transport only envelopes and small trucks only fridge-size packages. For this reason, our simulation results include an additional condition that the merchandise needs to be of the same type when clustering DOs into DSs. Hence given all the DOs of the day present in the database, our distance-based clustering is applied and bundles of DOs and DSs are put together based on some maximum distance of delivery locations and keeping in mind the delivery times and vehicle-type-package-type constraints. It is important to mention that the platform allows skipping of all these steps and loading DSs obtained through VRP-TW implemented in OPTILOG planner for the case when optimized routes can be imposed on the drivers of the carriers.

A separate module calculates the 'reserve' price for every generated DSs present in the OPTI-server database. This is a price representing the base (i.e. maximum, market value) price of a DS that a shipper is willing to pay. Here we use current practices and calculate this value for every DS based on various fix costs for each type of the package. For example, the prices used in our prototype version are envelope – 5€, box – 15€ and fridge-size package – 30€.

4.1 The auction managing module

The auctions are managed by a software module named OPTI-engine inside our marketplace server (i.e. OPTI-server). The main functions of the OPTI-engine range from publication of items in an auction, receiving and valuating bid offers to identification and assignment of DSs to carriers who win auctions. Several traditional methods for auctioning are included as closed-bid auction and Dutch auction, both with first and second prices. For first-price closed-bid auctions carriers place their bids simultaneously, where the bids correspond to monetary value for which they are willing to fulfil the DS that was put up for auctioning. In this case, the DS is assigned to the carrier that has proposed the most convenient offer (e.g. lowest offer). In second-price sealed-bid auctions as opposed to the previous case, the DS is assigned to the bidder that has offered the most convenient price but paying price is equal to the second-best bid. In the second approach, the Dutch auction or open descending-bid auctions, there is an auctioneer (i.e. administration or automated OPTI-engine) that performs the auction and iteratively receives offers as lower and lower bids from carriers, until no carrier is prepared to make a lower offer. Also for this auction type, first and second price methods are implemented. These are classical approaches where both auction types with different final price definition methods, in order to valuate different offers, take into consideration only the bid price without considering all the quality of the offered service.

In order to resolve this issue and take into consideration multi-attribute aspects of bids, we apply bid weighting, where carrier-relevant attributes are considered as price, punctuality, security, operating time and so on. The weight of each one of these attributes is either default for each carrier (i.e. parameters provided by express carriers) or defined based on historical information. The overall weighted combination of these factors is used further on for putting emphases on either shipper preferences or delivery cost minimization during auctioning through influencing the bid price (i.e. delivery cost for each bid). The final weighted factor is defined for each carrier within an auction, with values from 0 to 1, in order to appropriately weight the received bids from the carriers based on its characteristics and shippers' preferences.

4.2 The bidding agents module

An important software client component that is meant to help out the bidders (i.e. carriers) is OPTI-client carrier simulating the last-mile logistics company. Actually, each carrier in our system has a profile with his fleet of vehicles and specific characteristics for each one of them, as maximum volume and weight they can carry, their current position, current state of volume/weight saturation or the percentage of discount they can make based on current daily scheduling. A carrier with these characteristics can participate in an auction for assignment of DSs, which once won are further used for daily planning of his fleet's deliveries.

If during the planning stage the carrier receives notification of publication of an auction from the OPTI-engine the carrier needs to verify that inside of his fleet has one or more vehicles that can transport the load present in the DS that is being auctioned. A vehicle is capable of transporting a load if there is remaining space (i.e. volume) on the vehicle and weight of the overall charge doesn't exceed the limits of the vehicle. If yes, the carrier selects its vehicles and formulates bid prices for each one of the vehicles. This implies having specific discounts which model their behaviour in desire to obtain a fully planned vehicle schedule as soon as possible. In case he/she wins the DS put on auctioning, the carrier can incorporate it in his/her daily planning and modify the available discounts per vehicle.

In order to determine the bid value, the carrier needs to obtain the following information about candidate vehicles: the maximum percentage K_i of discount that he/she is willing to make for delivering with vehicle i based on already secured schedule; the remaining volume V_i and weight W_i that a particular vehicle i can carry; the average distance of the locations in the DS D_{ds} relative to the current position of the vehicle; volume of the load V_{ds} and weight of the load W_{ds} relative to the DS that is on auction.

The bid value BidValue_i for a particular vehicle i is calculated through the use of the 'reserve' price ReservePrice_{ds} for the DS on auction, as follows:

$$\text{BidValue}_i = \text{ReservePrice}_{\text{ds}} \times (1 - \text{Discount}_i) \tag{1}$$

$$\text{Discount}_i = \frac{K_i}{3} \times \left(\frac{V_{\text{ds}}}{V_i} + \frac{W_{\text{ds}}}{W_i} + \frac{1}{D_{\text{ds}}}\right) \leq K_i \tag{2}$$

From eqns (1) and (2) it can be noticed that the larger the volume and weight saturation are, the larger will be the applied discount.

5 SIMULATION SETTINGS AND RESULTS

The generic simulation was performed with 11,000 DOs covering the whole area of Milan for a duration of 10 days (~1,100 DOs per day). The cluster bundles were formed with OPTI-clus and on average cover areas of 600 m × 600 m with deliveries within 4 h temporal windows. This led to around 6,400 DSs that have been put on auction through the use of OPTI-engine. The number of carrier companies that registered with the marketplace has been set to 4, and each one of them has their own vehicle fleet (i.e. first carrier has six bicycles, second has four vans, third has two bicycles and two vans, and fourth has six small trucks). We focused on measures as the average occupancy varies for types of vehicles and the financial savings obtained by the auctioning mechanism. However, it is crucial to understand we are not only aiming to prove that auctioning mechanism works in city logistics but that the main stakeholders are incentivized to use it. The considered vehicle fleets are made out of three types of vehicles: bicycle (weight 35 kg, volume 0.05 m^3, envelopes); van (weight 770 kg, volume 4.2 m^3, envelopes, box, fridge-size packages); small trucks (weight 2,000 kg, volume 10 m^3, fridge-size packages). During the simulation, every carrier is fulfilling its own daily schedule for every vehicle; their overall aim is to obtain as many as possible DSs compatible with the characteristics of owned vehicles and have a fully booked daily schedule across the fleet with no empty hauls. As mentioned, the auction module was introduced not only to obtain more favourable prices and reductions for shippers but also to incentivized sustainability issues in urban logistics across carriers and allow them competitive advantage (Figs 2 and 3).

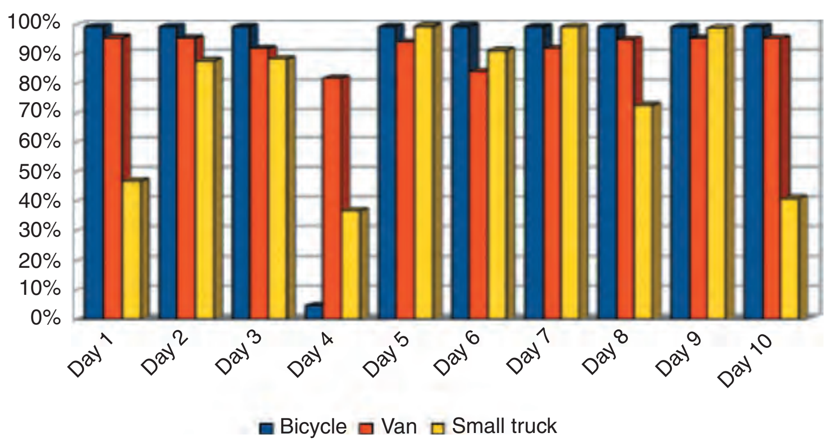

Figure 2: Average daily volume occupancy for different types of vehicles using the auction-based scenario.

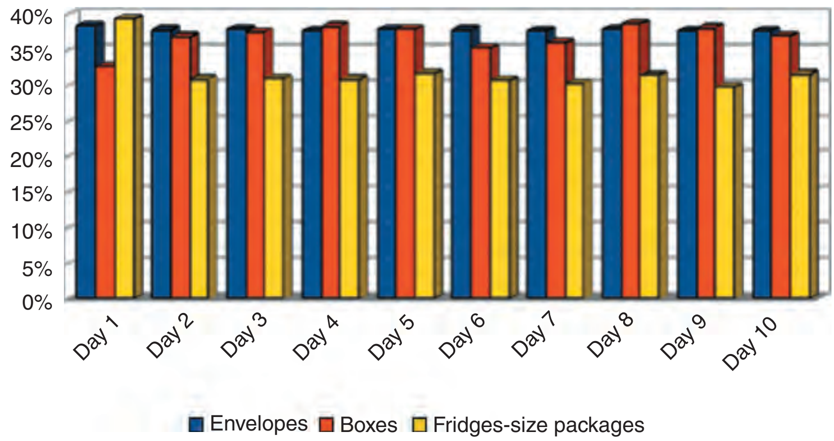

Figure 3: Daily savings for the shipper obtained using auction-based scenario (e.g. first-price Dutch auction).

After running different types of auction on our simulated data set we present main conclusions. We first calculate daily average occupation for every type of vehicle relative to their volume and weight. As expected, vans have almost always maximum occupancy of weight and at least 80% occupancy of volume as they can transport all three types of packages. While bicycles occupy almost all volume but almost never more than 5% of their maximum weight due to the type of the merchandise they can transport (i.e. only envelopes). Small trucks that can transport only fridge-size packages frequently occupy a lot of their volume and never less than 55% of their allowed weight. Clearly only vans can transport all types of merchandise they are able to optimize their loads. These results are as expected and the efficiency of running auction-wise scenario has been proved. Regarding the financial saving of shipper through auctioning DSs, we calculate average daily savings for different types of auction mechanisms and for every type of package, comparing the classical scheme of having fixed prices for each type of package.

We note that improvements can be seen by utilizing the Dutch auction type as opposed to the closed-price auction, as carriers have time to correct their strategy throughout iterations. What is interesting is that one can save up on all types of packages, for example for fridge-size packages on average we see savings of 27.87% while shipping envelopes give on average 37.6% savings compared to fixed cost scheme. Overall even though this is not the main objective of this work, using auction mechanisms will lead to possible reduction of the cost of transportation for shippers (i.e. express carriers) for all types of packages. As mentioned previously with this work our overall goal is not to drive down the fair market value and force carriers to underbid each other but to motivate carriers to be more competitive through introducing sustainable solutions for their vehicles and satisfying end customer conditions for DOs.

We aim at doing this by using a multi-attribute approach and tracing the delivery itself as well as feeding back to the system information and updates on punctuality, security, operating time, price – which on its own is influenced by gas emissions and fees needed to pay the LTZ and so on.

6 CONCLUSION

Modern digital marketplaces for urban logistics are still driven by traditional freight brokerage models while facing demanding requirements for on-time delivery and sustainability. In this article, we introduced a marketplace auction model that assigns loads to last-mile operators taking into account their characteristics and relying not only on the price of the shipment. Our contribution to a classical marketplace approach is twofold. First, we introduce a method for distance-based clustering to help out carriers valuate bids. This approach does not impose specific routes that carrier vehicles need to take but rather calculates the average distance and cost. Hence, its better suiting for last-mile carriers in city logistics represented mainly by association of independent carriers under contract where imposing a specific route or conditions on the delivery itinerary in terms of delivery sequence might present a major obstacle. Second, we present a multi-attribute approach to auctioning which besides classical advantages of competitive markets incentivize carriers to be more competitive not by directly reducing price but by using more sustainable vehicles and better customer satisfaction in the scope of city logistics.

ACKNOWLEDGEMENTS

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TRAFFIC MANAGEMENT OF MEGA INFRASTRUCTURE CONSTRUCTION PROJECTS: SUCCESS STORY AND LESSONS LEARNED FROM THE RIYADH METRO PROJECT

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ABSTRACT

The Saudi Arabian government is investing more than $22 billion to build a metro system in Riyadh, with a total length of 176 km across 6 lines and 85 stations. The metro network has been under construction since 2013 and is expected to be in operation by 2019. One of the biggest challenges faced by the authorities early on is as to how to manage traffic during the construction period especially that the metro lines running along some of the busiest corridors in the city. Specifically, the construction of Metro Line 5 was expected to cause major disruptions due to several reasons, among them are significant traffic volume uses this main road; wide extent of construction works (very large worksites, undertaken at busy junctions); concurrent execution of other infrastructure projects in the vicinity; and the presence of more than 20 government entities along the road. In this regard, a Comprehensive Strategic Traffic Management Plan for Line 5 was developed based on the state-of-the-art traffic management practices, supplemented by innovative and outside the box concepts. The plan included physical measures such as converting major roads into temporary one-way roads, parking management, junction improvements, modifications to traffic signals as well as soft measures such as shifting working hours for some government entities and a very aggressive community outreach programme. The plan was implemented in 2015, and was well received by the general public in addition to the key stakeholders. This article presents the thinking behind the development of this plan – including a benchmarking exercise against projects of similar nature/scale, adopted methodology, challenges faced, expectations of the plans' performance before implementation as well as the results after the implementation of the plan. This successful story could be a good case study for forward thinking of managing traffic in mega infrastructure and urban transport projects.

Keywords: largest metro project, mega construction works, traffic management.

1 INTRODUCTION

Riyadh city is the capital of the Kingdom of Saudi Arabia and is one of the largest cities in the Middle East with a population of around 6 million, which is expected to grow to 9.5 million by the year 2025 [1]. Recent growth patterns and future forecasts indicate that Riyadh will have very high population growth rates, which will lead to an increase in the demand for travel on its roadway network and transportation system. The daily vehicle trips in Riyadh in 2015 were estimated to be over 7 million trips/day, with more than 100 million kilometres travelled daily [2]. Travel forecast models, developed and maintained by the authorities in Riyadh, revealed that the continuous growth of the city would result in more traffic congestion on the city road network, which could affect the economic viability and sustainability of the city if not addressed sooner than later.

Sensing this urgency, in 2011 the government of Saudi Arabia allocated a budget of more than $23 billion to build a full metro network in Riyadh. The total length of the network is close to 176 km across 6 lines and 85 stations [3], covering most of the city of Riyadh, linking

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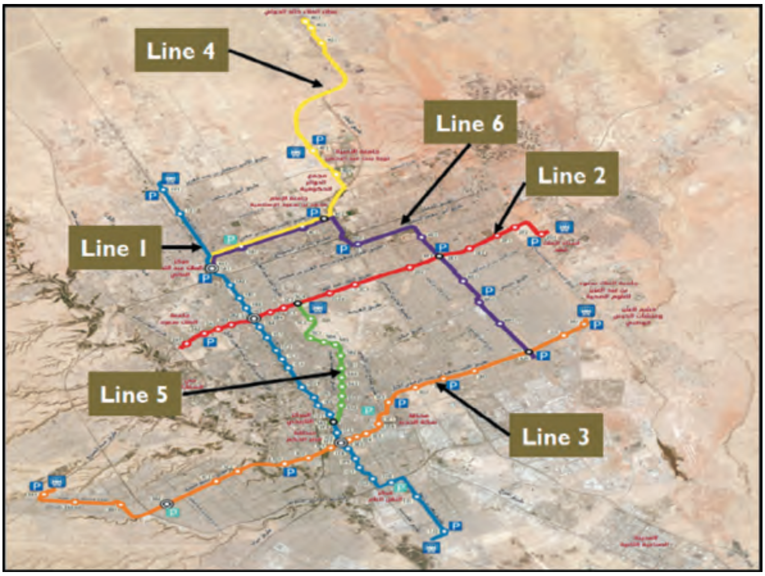

Figure 1: Riyadh metro lines.

the city centre to universities, the international airport, a newly built financial district and major commercial areas as shown in Fig. 1.

The metro project, along with a planned multilevel bus network, constitutes the very ambitious and aggressive Riyadh Public Transport Program (RPTP). The programme, which is managed by the Arriyadh Development Authority (ADA), aims at providing feasible and diverse mobility options for people in the city of Riyadh.

The metro project is likely the largest urban transport project in the world during its construction programme, incurring a lot of pressure on the city infrastructure and operation during the construction phase. Construction of the project started in 2013 and is planned to be completed by 2020.

The construction and delivery of the metro project was awarded to three different design–build contractors (DBC) as follows:

- Package 1: BACS consortium was awarded the design and build (DB) of lines 1 and 2 with a total length of 63.3 km of network.
- Package 2: Arriyadh New Mobility consortium was awarded the DB of line 3 with a total length of 40.7 km.
- Package 3: FAST consortium was awarded the DB of the remaining three lines (lines 4, 5 and 6), covering a total length of 72.5 km.

To facilitate the interaction between the owner of the project (ADA) and the DBCs, two project management/construction management (PMCMs) teams were retained by the ADA as the owner representative and to act as the interface between DBCs and the ADA. The organizational chart of the RPTP, as described earlier, is presented in Fig. 2.

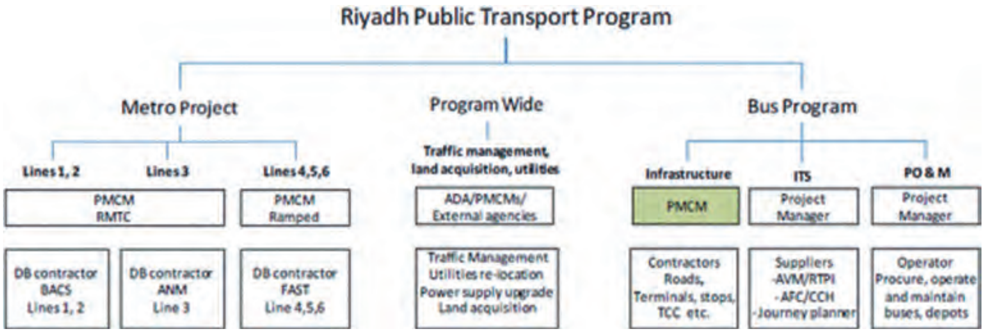

Figure 2: Organizational chart of the Riyadh Public Transport Program.

Due to the very tight and demanding construction schedule of the Riyadh metro and the fact that many construction activities affecting the roadway network are going to take place at the same time, there was a great focus on traffic management during construction to keep the city moving. As such, and to ensure the smooth implementation of the project and to minimize the adverse impacts on traffic conditions in the city during the metro construction phase, each DBC and each PMCM were required to hire traffic management consultants to develop traffic management schemes under which each metro line will be constructed. The foremost objective of these schemes is to minimize the adverse impacts on traffic conditions in the city during the construction period. Specifically, the construction of Metro Line 5 (running along King Abdulaziz Road (KAAR) in the heart of the city – see Fig. 3) was expected to cause major disruptions due to many reasons, which will be discussed later in this article.

Figure 3: Metro Line 5 alignment and stations.

Therefore, a Comprehensive Strategic Traffic Management Plan for Line 5 was developed based on the state-of-the-art traffic management practices, supplemented by innovative and outside the box thinking. The plan was gradually implemented in 2015 with great success and was well received by the general public in addition to key stakeholders.

This article presents the thinking behind the development of this plan, the process followed, challenges faced, adopted methodology, plans' performance before implementation as well as the results after the implementation of the plan. This success story could be a good case study for forward thinking of managing traffic in mega infrastructure and urban transport projects.

2 LITERATURE REVIEW

One of the requirements of the project is for each DBC to prepare their own traffic management plans (TMPs) and associated temporary traffic control plans (TTCPs) for each metro line in their package. This includes analysing and establishing the traffic management constraints and conditions under which each metro line will be constructed. In addition, each PMCM was required to hire a traffic management team (TMT) that would be responsible for reviewing, advising and approving TMPs and TTCPs submitted by the DBs to make sure these submissions and plans are consistent with the relevant and applicable policies and procedures.

Given the unprecedented and uncommon scale of the construction works (180 km of routes, 85 stations), it was essential before embarking on developing TMPs for this mega project to put into context all conditions, constraints, opportunities and best practices that relate to traffic management during construction, and especially those that would help in the case of Riyadh. In this context, the definition of what a 'construction work zone' or 'construction area' refers to was a key issue to deal with early on, given the local conditions associated with this project. Several definitions can be found in the literature, such as the one by Karim and Adeli [4] where they defined a work zone as 'a region within an existing highway's roadway where active maintenance, rehabilitation, and/or reconstruction work is carried out'. Other definitions that are more applicable to the case of Riyadh is the one provided by HCM 2000, which defines a work zone as 'a segment of highway in which maintenance and construction operations impinge on the number of lanes available to traffic or affect the operational characteristics of traffic flowing through the segment'. Since the traffic impact of the construction work zones of the Riyadh metro project was expected to far exceed the area delimited by construction activities, it was concluded that the definition provided by HCM 2000 is more applicable to the case of Riyadh.

From that perspective, the TMT not only reviewed international best practices in the area of traffic management during construction works specifically but also looked at traffic management concepts in general (i.e. those measures and schemes that are typically used to solve severe traffic congestion problems – in mega events – not necessarily during construction). In addition to that, the team reviewed relevant standards/manuals, so as to learn from these resources and try to benefit from them in the context of the Riyadh metro project.

In terms of traffic management in mega events, the team reviewed the traffic measures adopted in the Olympic Games that were held in London in the summer of 2012, which attracted millions of athletes, spectators and tourists. At the transportation system/traffic management level, in addition to several traffic management schemes, the Olympic Park was served by a dedicated rail shuttle service, called the Olympic 'Javelin', which was designed to transport 25,000 spectators per hour [5, 6]. The team also reviewed the traffic management schemes that were implemented in the 2010 World Cup in South Africa [7, 8], and the 2008 Beijing Olympics [9–12].

In terms of traffic management during construction, several TMPs from around the world were reviewed, varying in scale and context. Some of the reviewed studies included TMP for the construction of Foxground and Berry Bypass (FBB) in NSW, Australia [13], which describes how to safely manage vehicular, cyclists and pedestrian traffic during the design and construction phase of the FBB project; TMP for the construction of MacKays to Peka Expressway Project in New Zealand, which is a 16 km new expressway [14]; and project TMP for the construction of the Port Botany Expansion Project in Sydney, Australia [15]. The knowledge gained from reviewing those resources helped in forming a better understanding of the approach that should be followed towards addressing the traffic impacts associated with Riyadh metro.

3 THE PROCESS

In the case of Metro Line 5, from the beginning it was realized by the Client, PMCM and the DBC that the traffic challenges on this specific metro line would require a collaborative team effort rather than a PM/contractor relationship. Therefore, the traffic teams of both the PMCM and the DBC worked as a cohesive unit to come up with an agreed-on, well-studied TMP for Line 5. In this respect, the combined traffic team followed a clear and sequential process as follows:

1. Developing an understanding of the project's and Line 5 traffic and transport issues, challenges and opportunities
2. Developing a TMP for Line 5 (including a logistics plan) and associated TTCPs
3. Managing the implementation of the TMP and TTCPs
4. Managing any updates to the TMP and TTCPs (whenever future updates of the TMP occur)

Throughout the process, liaison and coordination with all stakeholders, including DB construction team, client, relevant stakeholders and other metro/bus packages, was an essential activity of the entire effort.

4 DEVELOPMENT OF LINE 5 TRAFFIC MANAGEMENT PLAN

4.1 General concepts

In coordination between the PMCM and DB traffic teams, a TMP for Line 5 was prepared. The plan sets out, among other items, the overall project timetable, construction methods, proposed major traffic management schemes (TTCPs) anticipated and initial logistics plan. The information provided in the TMP identified what constraints may need to be applied in terms of construction timing or method, where it has a bearing on traffic management. The TMP also identified hard and soft mitigation measures that may be required to mitigate the expected adverse traffic impacts.

Throughout this process, the traffic team was in continuous coordination and liaison with both the client (ADA) and the construction team to make sure that both parties fully understand the requirements of the elements of the traffic management plans developed by the traffic team to avoid any disruptions.

The TMP sets out the following traffic impact assessment procedure to be followed in developing the alternatives for traffic management schemes:

- Step 1 – Define study area and site appraisal
- Step 2 – Define traffic surveys' work

- Step 3 – Analyse Existing Traffic Conditions
- Step 4 – Traffic modelling work
- Step 5 – Analyse impact of construction works on area of influence of project site
- Step 6 – Develop mitigation measures.

4.2 The challenge

From the start, it was clear to everyone that the construction of Metro Line 5 was expected to cause major disruptions to the traffic patterns in and around KAAR due to the existing significant traffic volume and congestion on the road, since it is one of the major corridors in the city. In addition, the number of underground stations is significant on this line which would lead to very large worksites along the road, and the closure of very busy junctions on the roadway network during the construction phase. The effect of this construction work is compounded by the presence of concurrent metro and other infrastructure projects in the vicinity. Metro line '5' is shown in Fig. 4.

Therefore, it was understood that a solid start-up process with the key parties involved in this project (PMCM teams, TMC, DB contractors and other stakeholders), as well as a common understanding of the project requirements, relationships, inter-dependencies, communication channels, activities and the expected outcomes should be achieved. Taking into consideration the significant size of this project, the initial period of the project was dedicated by the traffic team to gain a clear and comprehensive understanding and appreciation of the project, including:

- understanding the project site(s), constraints, size and magnitude;
- understanding the roles, responsibilities and requirements of the DB contractors, PMCMs as well as other stakeholders;

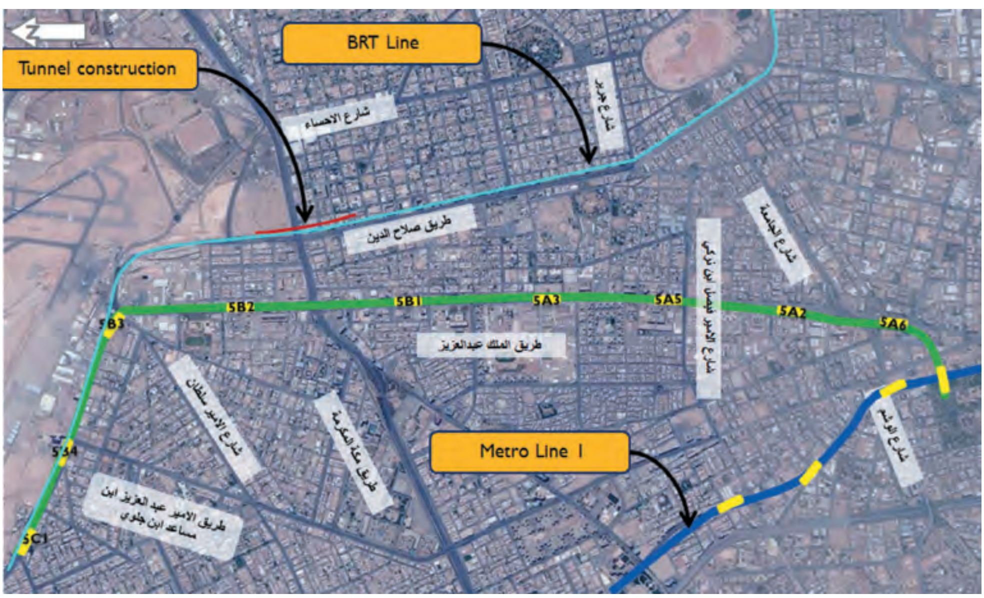

Figure 4: Line 5 traffic challenges.

- understanding the main implicit and explicit relationships between project milestones and their impact on the traffic management schemes;
- understanding of the key stakeholders that may be affected by the construction works. In this respect, all major stakeholders along the alignment of the line were identified, which included the headquarters of around 10 ministries (Ministry of Defence alone have more than 15 facilities other than its headquarters).

Overall, this phase involved the following activities:

- Review of project documents and background material: the aim of this activity was to review all available project documents as well as background material (such as project background and overview, information on other concurrent projects in Riyadh, etc.) in order for the traffic team to acquaint itself with the project and its anticipated volume of work.
- Site reconnaissance: site visits were conducted by the traffic team to acquaint itself with the project sites and to record observations related to traffic that might be of interest during project implementation.
- Coordination and liaison: this was a key activity that started early in the process and continued throughout the project implementation period with all key stakeholders, especially the public and private entities affected by the construction works along Line 5.

4.3 The opportunity

To develop the traffic management plan during the construction phases, the focus was on better utilization of the surrounding roadway network. This was mainly due to the travellers' behaviour which preferred using the main roads to the surrounding local roads even if this was associated with more travel delays. The Riyadh Strategic Model (developed using EMME software) was used for this purpose to better understand the impact of construction works of Line 5 on the surrounding areas. The aim was to assess and validate the traffic flow changes that are expected to occur as a result of the construction works and associated closures. This is illustrated in Fig. 5, extracted from the Riyadh Strategic Model, which shows the peak AM V/C along KAAR and the surrounding secondary roadway network.

The effect of the construction works on the operating conditions and the traffic volumes/patterns on the surrounding network were modelled using the EMME software and the results are shown in Fig. 6. The results show that traffic is naturally diverted to parallel and adjacent roads when the closures at station locations on KAAR are imposed. The roads where traffic was diverted were identified as the candidates for further study and analysis to improve their performance to accommodate the diverted traffic from KAAR. Not only that, but this early exercise enabled the team to define a clear study area for Line 5 TMP that is bounded by the main roads affected, as shown in Fig. 7.

4.4 Traffic surveys and site appraisal

In addition to the site appraisal programme (not discussed here due to lack of space), traffic count data were collected on the links and junctions within Line 5 study area as shown in Fig. 8. The existing traffic volumes were obtained based on a programme of traffic counts and road inventory surveys that were conducted prior to the commencement of construction works. The data collected included:

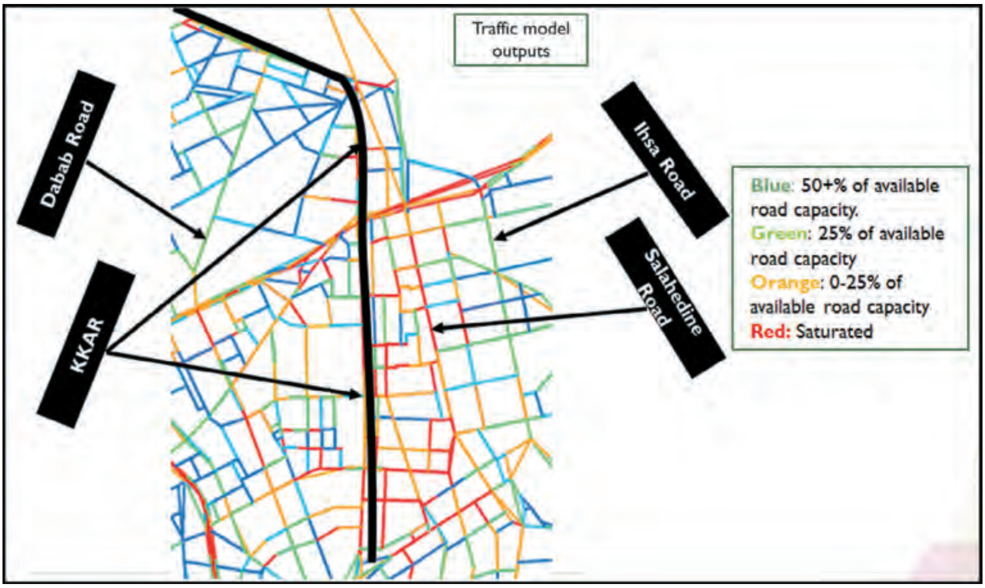

Figure 5: Line 5 strategic model output.

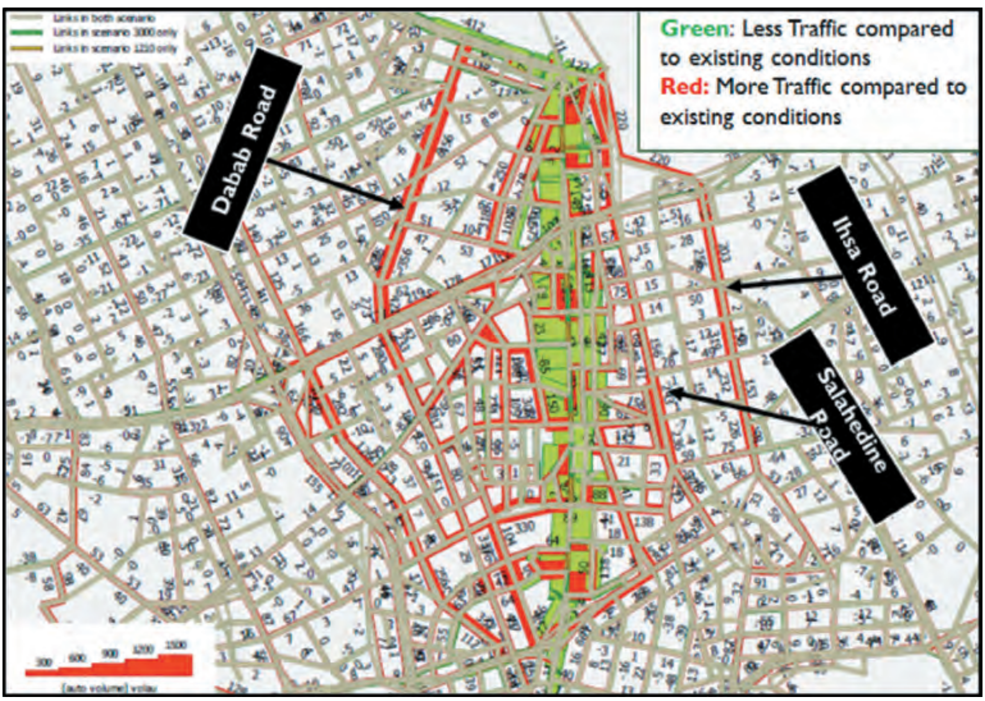

Figure 6: Impact of construction activities on traffic patterns.

Figure 7: Line 5 study area.

Figure 8: ATC and TMC location on Line 5 subarea.

- Thirty-five locations of automatic traffic count (ATC) with vehicle classification (heavy or light vehicles) and continuous 24-h data collection.
- Thirty-five locations of turning movement counts (TMC) with vehicle classification as well.

Moreover, a traffic signal survey was carried out in the whole subarea network, checking the allowed movements, cycle time, phases, etc. Based on these times and the TMC counts, the

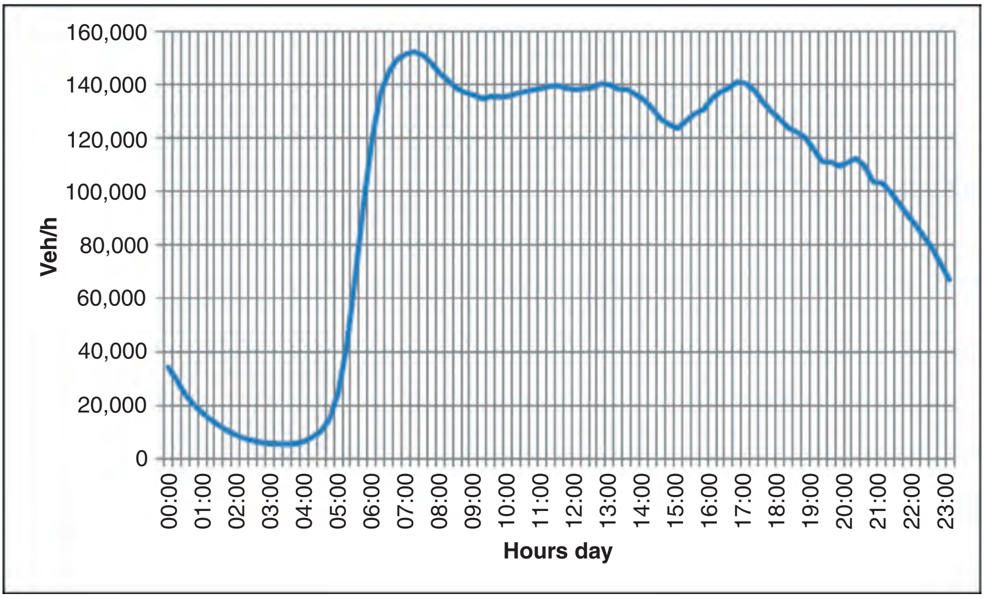

Figure 9: Daily traffic profile from ATC counts.

existing conditions on the road network and affected junctions were extracted. Based on collected traffic counts data, the peak hours were identified as 7.15–8.15 am and 16.45–17.45 pm. Figure 9 shows the traffic profile during 24 h based on free-flow conditions from ATC.

4.5 The approach and strategy

During the development of Line 5 traffic management plan, the focus was on minimizing (to the extent possible) the impact of the construction activities on the roadway network operating conditions, while ensuring the smooth implementation of the project (on time and within budget). Due to the demanding work schedule, it was concluded that a Single Comprehensive Traffic Management plan needs to be developed during the period of construction of Line 5 to minimize confusion and disturbance to citizens caused by frequent changes to traffic schemes. The strategy took into consideration the following:

- The plan integrated other infrastructure activities in the area and diverted traffic to parallel unutilized roads.
- Where possible, relocate construction activities away from the road network (such as Tunnel Boring Machine (TBM) shafts).
- Regional (i.e. through) journeys should be diverted away from KAAR via parallel high-capacity roads (i.e. strategic diversion routes).
- Provide local diversion schemes to maintain accessibility to KKAR.
- Maintain accessibility to all facilities along KKAR.
- Identify potential mitigation tools.
- Ensuring safety for all users at all times.

4.6 The mitigation measures

The traffic team identified a set of possible mitigation measures that have the potential to minimize the negative impacts of construction in order to achieve an acceptable performance of the road network during the construction period. These mitigation measures include the following:

- 'Hard' physical measures that are aimed at providing improvements to road capacity, or at the very least smooth traffic flow around construction work areas through the introduction of temporary fixed elements that do not change frequently.
- 'Soft' management measures that are aimed at managing (or even suppressing) the demand for travel and may include more dynamic schemes to manage traffic and/or travel habits.

A number of hard measures were contemplated; some of the key measures included:

- Temporary bridges:
  - Along station construction boxes
  - Along relief roads
- Road capacity enhancements
- Temporary one-way roads
- Junctions improvements
- Modifying and/or removal of parking
- New U-turns to replace banned left turns
- Traffic signals:
  - New traffic signals
  - Modifications to existing traffic signal timings (coordinated signals, Green Wave, signal optimization, etc.)

The 'hard' measures were contemplated on a site-by-site basis, and after having undertaken site visits to assess the traffic conditions and site constraints in all areas affected by construction. All the hard mitigation measures were used except the temporary bridges, which were not feasible at the identified locations due to more than one factor (impact on construction activities, time requirements, etc.).

As for 'Soft' measures, the objective is the promotion and provision of measures aimed at decreasing the levels of traffic volumes and movement patterns in the peak hours to cause a reduction in the use of the private car or to encourage people (by providing them with relevant information on a timely basis) to follow a specific pattern of movement in a way that results in balanced distribution of travel around the city. The identified soft measures included:

- Flexible or staggered working hours to reduce congestion at peak times. Those can be specific to schools and government authorities.
- Providing traveller information tools, including intelligent transportation system improvements, mobile and social applications and other methods.

The flexible or staggered working hours' proposal was dropped by the authorities due to several legal issues that would have made it very hard to obtain approvals on such measures from government authorities. The only 'soft' measure that was implemented is the launching

Table 1: Performance of selected TMP.

KPI	Base conditions	Selected plan
Delay time (s/km)	214.11	183.6 (−15%)
Flow (veh/h)	76,328	78,256
Stop time (s/km)	192.41	158.94 (−18%)
Travel time (s/km)	264.91	235.2 (−11%)

of a mobile application (called Delilat Arriyadh), similar in functionality to Google Maps, where all metro traffic management schemes and detours were updated very frequently so that users could use this application to choose their routes.

4.7 The final traffic plan

After testing several iterations of different concepts and proposals using the traffic model, a final TMP for Line 5, which achieved the best performance, was adopted. The process of the plan development also included hundreds of coordination meetings and workshops with stakeholders ranging from ADA top management, traffic police, Ministry of Transport and government officials to local businesses and residents. The success of the plan is mainly related to an exhaustive and extensive effort by the traffic team, supported by the endorsement of the client (ADA) to get everyone involved on-board with the plan.

Table 1 presents the traffic analysis results of the adopted plan in comparison to the base conditions. Surprisingly, the overall traffic performance of Line 5 TMP exceeded the base conditions. This was one of the big achievements of this plan, whereby optimizing the road network resulted in a better performance of the road network even with a closure of one major arterial in the city.

Figure 10 presents the overall traffic management plan for Line 5 that was implemented on site.

4.8 Observations after implementation

After implementing all components of the plan, all parties involved agreed that the plan outperformed expectations, especially with travellers getting familiar with the new traffic management arrangements faster than expected. In fact, there have already been some calls to keep some of the implemented traffic management schemes to be long term after the completion of the construction works due to the improved performance and accessibility in some areas of the study area.

5 SUMMARY AND CONCLUSIONS

The Saudi Arabian government is investing more than $22 billion to build a six-line, 176 km, 85-stop metro system in the capital city of Riyadh. One of the biggest challenges that were identified early on is as to how to manage traffic in the city during the construction period especially that all six metro lines run along busy corridors. One of the most critical lines is Metro Line 5 along KAAR in the heart of the city. The construction of this line was anticipated to cause major disruptions due to the significant traffic volume using this major arterial road, the large construction works required at main junctions as well as the

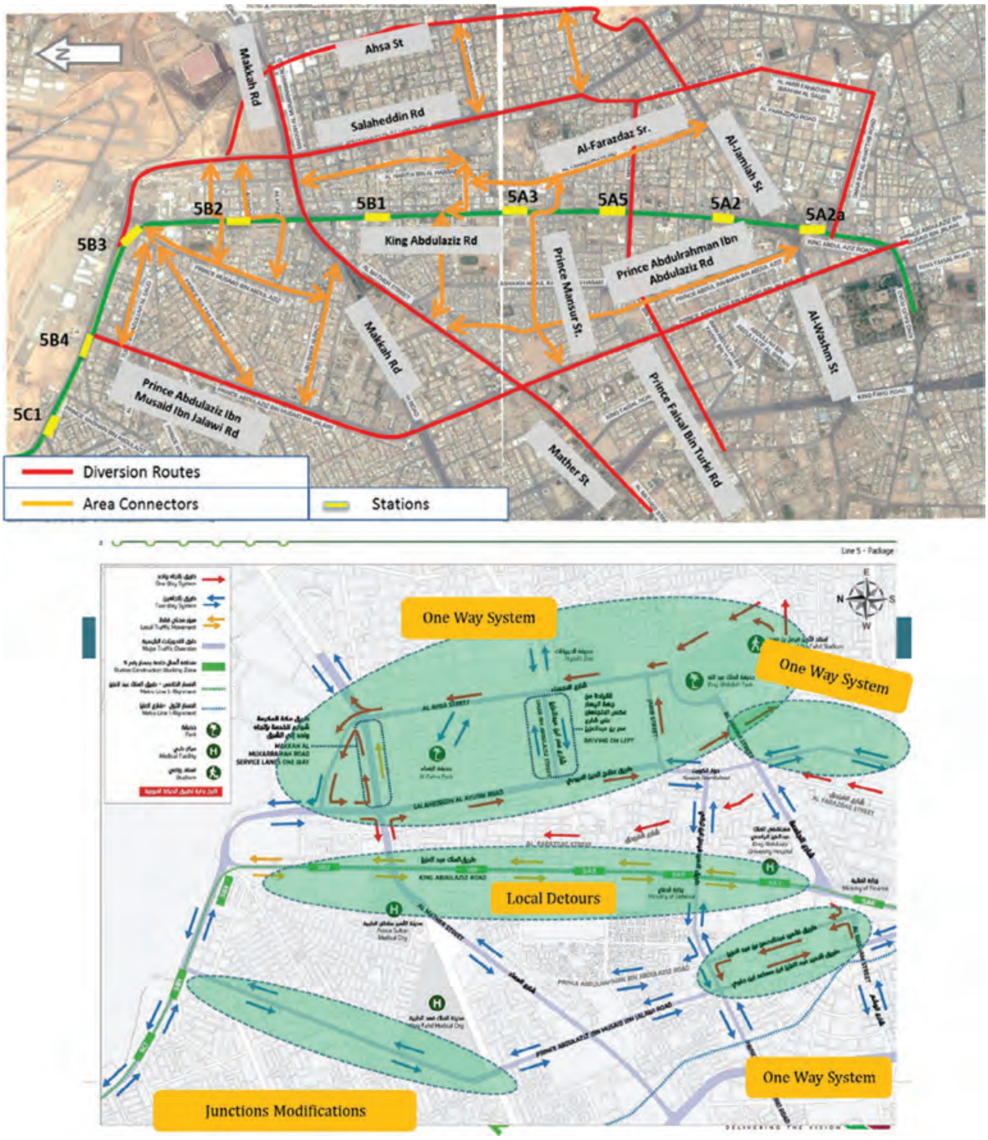

Figure 10: Line 5 final traffic management plan.

concurrent execution of other infrastructure projects in the vicinity of the road. The traffic team responsible for this line developed a Comprehensive Strategic Traffic Management that addressed the challenges, optimized opportunities and used state-of-the-art traffic management practices supplemented by innovative and outside the box concepts. The plan included aggressive physical measures such as converting major roads into temporary one-way roads, improvements to traffic flow and a very aggressive community outreach programme. The plan was implemented in 2015 with great success and is expected to stay throughout the project duration.

The success of the plan depended largely on combining local knowledge of the city traffic conditions, using proven traffic modelling approaches to guide the thinking process, proposing aggressive mitigation measures to minimize the impact of the project with such a large size, and managing a large number of stakeholders efficiently and concurrently. This successful story could be a good case study for forward thinking of managing traffic in mega infrastructure and urban transport projects.

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ESTABLISHING THE RELATIONSHIP BETWEEN RAILWAY SAFETY AND OPERATIONAL PERFORMANCE

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ABSTRACT

Deregulation and/or privatization of railway systems has been adapted in many developed countries, aimed at improving economic performance. Literature on railway performance mainly focuses on the effects of reforms and on liberalization itself as well as measuring performance indicators for the management of assets in the railway industry. Although these management reforms on the maintenance and operations of rail infrastructures are generally found to have contributed to improving trends of rail safety and safety performance, there is not much evidence from research to support this. There is also little work on how the lessons from restructuring can apply in developing countries.

Identifying approaches that can revitalize railways in developing and emerging economies while raising standards of safety and operational performance is the objective of this article. Presented are some of the specific lessons from developed countries and how they can be applied in developing economies' railways, noting that it is not generally feasible to adopt best practices because of social and/or economic constraints. Only where there is a significant foreign investor is there the potential to replicate best in class technology and operational practices, so the presentation will identify areas where less well-funded railways can adopt lessons from developed countries – using both historical and current international benchmarks.

The originality of this approach lies in establishing the relationship between performance and safety in the era of reforms and liberalization of the rail industry. The article analyses publicly available data to suggest how rail safety considerations have impacted in a more general way upon railway performance, and by extension, derive lessons for emerging and developing economies.

Keywords: benchmarking, operational performance, railway, safety, safety performance

1 INTRODUCTION

Cities all over the world are growing rapidly with ever more intensive human interactions, dense vehicular flows and vigorous commercial activities. In many cities, faster, more reliable and efficient modes of transport are required to support the sustainable growth and development of their economies. Unfortunately, many developing and emerging economies are lagging in the provision of sustainable transport means for their people.

The growth and development of the railway industry in many developing countries has been extremely slow since its inception more than a century ago. Railways are now the least developed mode of transport as road transport is the dominant mode in most of these developing countries. As a product of the colonial period, railways of tropical Africa were built from ports into the inland to facilitate the export of minerals and agricultural products as well as the import of finished goods [1, 2].

Although rail networks are identified as an important element of the transportation system for economic growth and development of many countries, Ghana's rail network, like some other rail networks in developing countries, has not changed since the 1960s [2, 3]. Bullock [1] in his study on sub-Saharan African railways describes the existing African railway system as fragmented with lines connecting cities within a country or originally linking a port to its immediate hinterlands despite proposed master plans for an integrated rail system. It must be noted that this is not the case for all rail networks in Africa as there are a few significant international networks such as the North African network in

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Maghreb linking Morocco, Algeria and Tunisia; South Africa's network which extends to the Democratic Republic of Congo and Tanzania; as well as the East African rail network linking Kenya, Uganda and Tanzania.

Over the years, rail transport in developing countries has seen a decline in passenger numbers and passenger kilometres travelled because of competition from road transport [1–3]. Although traffic densities are generally low, specialized mineral lines in West and Southern Africa carry more than half of sub-Saharan railway's total freight measured by net ton-km [1]. The decline in patronage of rail transport is mainly attributed to the neglect of the railway sector by governments, involving poor quality of service, insufficient funds for expansion projects, deteriorated assets and poor maintenance of tracks and locomotives as a result of the lack of skilled personnel leading in some cases to the collapse of the rail industry in most of these developing countries.

In this regard, the absence of an established railway authority or regulator for the safe operation and maintenance of the almost non-existent rail networks poses a great risk to passengers, workforce and the general public. South Africa's Rail Safety Regulator (RSR) is possibly the only sub-Saharan African country with a well-established rail safety regulating body. As a custodian of rail safety on South African railway lines, the RSR is responsible for the issuance and management of safety permits, the investigation of railway accidents, the conduct of inspections and audits, the development of regulations and safety standards for the formulation of regulatory regimes as well as the issue of notices of non-conformance and non-compliance [4].

With plans in place to rejuvenate the railway systems of developing countries in order to boost economic growth and development; the applicability of best practices of rail operations from developed countries is recommended. To do so an understanding of the physical, social, economic and political environment in which these systems will operate is very necessary and highly required.

2 RAILWAY PERFORMANCE DATA

By presenting a case study of the British railway network (which has a vast amount of publicly available data) this provides the opportunity to grasp an understanding of key performance indicators as well as help define the parameters required to establish a more detailed understanding of the relationship between railway safety and operational performance. In this respect, the main units of analysis for this study are passenger train operating companies (TOCs) and the railway network infrastructure management companies of Britain's railway industry.

Great Britain's railway is generally acknowledged to be the safest major railway network in Europe and among the safest in the world, as demonstrated by data published by the Office of Rail and Road (ORR). ORR is 'the independent safety and economic regulator for Britain's railways as well as monitor of Highways England' publishes a great deal of statistics on railway performance, rail usage and safety [5, 6]. According to Gower [7], passenger performance is assessed using performance metrics such as the Public Performance Measure (PPM) and Cancellations and Significant Lateness (CaSL) with the performance data supplied by Network Rail. Network Rail is Britain's dominant railway infrastructure management company and hence the source of all infrastructure-related data used in this analysis.

The PPM is a key performance metric for the evaluation of overall performance and reliability of train services. This therefore makes it 'the main cross-industry measure of operational performance for all passenger services' [8]. It is defined as the percentage of passenger trains that arrive at final destinations on time. That is, trains that arrive at their final destination within 5 or 10 min (for long-distance services) of their scheduled arrival time [7]. Similarly, CaSL is defined as the percentage of passenger trains that are cancelled either in part or full and/or arrive at final destinations 30 or more minutes later than the scheduled arrival time [7, 9]. It was developed as a supplementary measure to ensure that trains are not 'written off' by companies once they exceed their PPM threshold [8]. It is a very useful measure in terms of performance recovery and also incentivizes companies and their controllers and signallers to ensure that trains do not arrive later than 30 min. The term cancellation is used when a train fails to depart from its point of departure or when a train is terminated before it reaches its destination. Two main types of cancellation according to ORR [8] are as follows:

- Full – where the train failed to run entirely or ran less than 50% of booked mileage or called at less than 50% of booked stations. Trains that arrive over 119 min late are counted as full cancellations.
- Part – where the train terminated short of destination or started beyond origin (or both). Trains that fail to call/stop at, at least one booked station are counted as part cancellation.

In addition, a moving annual average is calculated for both PPM and CaSL to reflect the proportion of trains on time as well as those cancelled or significantly late within the last 12 months. In calculating the CaSL data, the total number of passenger trains cancelled and significantly late between 30 and 119 min is divided by the number of scheduled trains, which is then expressed as a percentage [8]. The lower the figure, the fewer the CaSL of passenger train services. The ORR also publishes total delay minutes by TOC which reflects performance of the individual TOCs. The total delay minutes are further categorized into Network Rail-on-TOC-related delays, TOC-on-Self-related delays and TOC-on-TOC-related delays. PPM, CaSL and total delay minutes categorized by TOCs are therefore the operational performance data used in the study.

Generally, safety is measured by the number of accidents and its consequences that may occur at home, the workplace, school or on any mode of transport. In the British rail industry, rail safety is measured by the fatalities and weighted injuries, hence the reporting of occurrences in the operation of trains and maintenance of railway infrastructure is the major source of rail safety data. There is therefore the need to link the number of accidents and the related number of victims to rail traffic performance to measure relative safety [10] often expressed in passenger-kilometres and ton-kilometres. According to Network Rail [9, 11] the passenger safety indicator is used to measure the level of passenger safety on a network and it is derived from two data sources. These are the train accident risk data from the Precursor Indicator Model (PIM) and the weighted fatality and injury data from station level crossings and Network Rail managed stations [9].

The PIM, provided by the Rail Safety and Standards Board (RSSB) on a quarterly basis, tracks changes in accident precursors to measure the underlying risk from train accidents and is also calibrated against the safety risk model (SRM) [12]. Due to the rare nature of train accidents, precursors help indicate the risk of accident occurrence although more often than not, these do not result in an actual accident. PIM therefore demonstrates quantified changes in the underlying risk over a period. In other words, it provides a day-to-day review of the main elements of train accident risk, that is the risk of collisions, derailments and fires [12], which are reported/recorded by TOCs into the RSSB's Safety Management Intelligence System (SMIS).

According to the UK Health and Safety Executive (cited in [13]), 'an accident is any unplanned event that results in injury, and/or damage and/or loss'. Alternatively, a precursor is an event or condition which indicates the existence of a higher level of risk or a top event which is often defined as a serious incident that may be the immediate cause of a death or injury [13, 14]. The difference, however, between accidents and top events is the consequence of the event. That is, a top event qualifies as an accident only in situations where there are injuries, death or serious damage to property [12].

Risk, in the context of the RSSB's SRM, is 'an estimate of the potential harm to passengers, staff and members of the public from the operation and maintenance of the railway' [15]. Therefore, the risk (the average number of fatalities or equivalent fatalities per year) associated with an event is calculated as the product of the frequency and consequences. That is:

$$\text{Risk (FWI/year)} = \text{Frequency (events/year)} \times \text{Consequence (FWI/event)} \quad (1)$$

Signal passed at danger (SPAD) risk data is an example of data that can be found in SRM. Other precursor indicator measures in SRM are infrastructure failures, infrastructure operations, train operations and failures and/or level crossings. For the purpose of this research, SPAD risk rates will be the measure of safety performance due to data availability at the time of the study. The choice of parameters has been based on the availability of data within a significant period (preferably 2006–2016) for which the data will have the ability to reflect trends or patterns for meaningful comparison/analysis.

Out of a total of 25 passenger TOCs operating on British railways, serving as a sampling frame, focus is placed on 17 franchised TOCs based on the availability of SPAD risk data between the time periods 2006–2016. SPAD risk data is significant to this research as it is an important element of railway safety performance. According to the European Railway Agency [16], 'a safe railway is more efficient and a more attractive transport choice, enabling society to address the environmental and economic challenges of the 21st century'. In Europe, the European Union (EU) member states are required by the EU Railway safety directive (2004/49/EC) to ensure the maintenance of safety as well as continuous improvement where reasonably practicable [17, 18].

3 FINDINGS AND DISCUSSIONS

Testing the defined set of parameters below is mainly aimed at determining mathematically/statistically the existence of a relationship between railway safety and operational performance. Using available data from the ORR and RSSB on the selected 17 TOCs with respect to PPM, CaSL, TOC-on-Self-delay minutes and SPAD risk rates, the processes involved in establishing a correlation are discussed. It must be noted that TOC-on-Self-delay minutes are first used based on the notion of focusing on parameters within the managerial control of TOCs.

3.1 Hypothesis test

H_0: *safety and operational performance are independent*
H_1: *safety and operational performance are (negatively or positively) associated*

First, TOCs were ranked by performance for each performance indicator (both safety and operational performance data) per year over the 10-year period as illustrated in Table 1. It must be noted that, for a high-performance ranking of 1, PPM was based on the highest

Table 1: TOCs performance ranked for the period 2006–2016 using ORR available data (Source: Author's Construct, 2016).

	2006				2007			2008			2009			
Passenger Train Operating Company	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes
Arriva Trains Wales	86.50	4.49	100	91.81	2.88	0.58	9251	2.65	0.99	265,531	94.89	186	0.48	206,581
c2c	94.15	2.23	100	94.50	2.88	0.00	9486	2.05	0.49	25,549	96.21	138	0.47	20,572
Chiltern Railways	93.98	1.57	100	94.37	1.90	0.34	9527	1.39	0.50	45,041	95.48	143	0.32	54,009
CrossCountry	85.01	6.92	100	86.32	6.79	0.50	8952	5.10	0.32	123,663	90.69	459	0.65	96,886
East Midlands Trains	86.56	3.52	100	86.54	4.56	0.27	8838	3.57	1.04	129,044	92.35	223	0.22	107,383
First TransPennine Express	88.34	4.83	100	91.57	4.14	0.55	9014	4.71	0.31	–	92.30	346	0.69	–
Govia Thameslink Railway	89.48	2.83	100	89.27	2.93	0.00	9104	2.56	0.00	503,904	89.97	338	0.00	528,805
Great Western Railway	84.02	3.34	100	82.39	4.57	0.94	8897	2.58	0.69	370,583	92.27	231	0.49	383,577
Greater Anglia	87.37	2.57	100	89.80	2.44	0.91	9070	2.15	1.09	216,498	91.07	229	0.95	212,798
London Midland	86.57	3.23	100	88.42	3.29	4.41	8755	3.75	0.74	199,242	88.37	343	0.76	175,070
London Overground	91.29	3.52	100	91.06	3.75	21.08	9275	2.11	140	50,805	92.69	250	1.86	45,957
Merseyrail	92.56	3.11	100	94.29	2.65	1.38	9469	2.53	1.08	32,364	96.22	191	0.80	23,643
Northern	87.18	2.23	100	88.31	2.53	0.65	8915	2.56	0.90	590,166	91.70	197	0.69	569,669
ScotRail	88.56	2.17	100	90.11	2.17	1.08	9085	2.16	0.53	265,450	90.58	222	0.42	306,232
South West Trains	90.48	2.34	100	91.47	2.02	1.18	9328	1.80	100	230,986	92.95	222	0.51	236,317
Southeastern	88.69	2.05	100	89.62	2.23	1.48	9100	1.99	114	322,033	90.05	306	0.88	320,135
Virgin Trains West Coast	87.19	4.38	100	85.89	5.20	0.21	8247	7.06	0.36	101,571	82.89	671	0.09	121,833

	2010				2011				2012				2013			
Passenger Train Operating Company	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay minutes	PPM	CaSL(%)	SPAD Risk Rate	Celay Minutes	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay minutes	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes
Arriva Trains Wales	9427	2.28	0.91	230,217	93.79	2.41	0.91	241,469	93.52	241	0.76	219,276	9336	250	0.83	212,023
c2c	9509	2.04	0.00	24,257	96.57	1.42	0.24	15,049	97.44	102	119	17,770	9691	132	0.72	14,065
Chiltern Railways	9426	1.69	0.84	73,087	92.78	1.92	0.48	102,385	94.67	144	0.29	77,137	9510	134	0.14	66,903
CrossCountry	8798	5.58	0.46	95,709	89.08	4.44	0.20	68,047	87.80	539	0.15	71,354	8729	475	0.25	74,597
East Midlands Trains	9214	2.49	0.36	98,469	93.11	1.94	0.43	72,094	93.18	213	0.72	81,781	9118	278	0.43	92,513
First TransPennine Express	9068	4.44	0.29	21,820	93.03	2.78	0.29	16,383	92.80	305	0.38	16,995	8992	492	0.10	16,841
Govia Thameslink Railway	8914	3.60	0.00	517,051	90.29	2.91	0.00	515,373	88.95	303	0.00	564,987	8673	423	0.00	555,950
Great Western Railway	9075	2.66	0.68	364,648	90.33	2.48	0.53	329,205	89.54	289	0.68	354,218	8871	298	0.61	333,713
Greater Anglia	8904	2.66	0.45	242,507	89.70	2.40	0.83	209,811	91.04	225	0.47	183,547	9039	250	0.90	166,302
London Midland	9008	2.65	0.55	164,595	89.85	2.73	0.49	142,739	87.74	355	0.55	207,286	8514	384	0.66	201,446
London Overground	9384	2.68	0.67	68,214	95.72	1.83	2.14	47,823	96.10	168	110	40,223	9560	188	1.83	40,707
Merseyrail	9535	2.06	2.38	36,078	95.07	2.09	1.23	31,123	95.32	236	0.49	36,361	9560	186	1.23	39,354
Northern	9064	2.24	0.79	556,043	91.53	1.88	0.68	509,436	91.35	185	0.39	528,228	9048	190	0.78	501,340
ScotRail	8996	2.76	0.73	364,858	89.78	2.89	0.88	288,746	92.93	161	0.36	254,477	9108	205	0.46	279,952
South West Trains	9343	1.75	1.05	193,814	92.54	1.97	0.85	207,888	91.62	207	0.60	212,368	9068	251	0.85	211,626
Southeastern	8769	3.85	1.11	364,742	91.43	2.36	1.09	316,545	91.60	225	0.76	285,608	8979	301	0.77	286,684
Virgin Trains West Coast	8549	5.56	0.31	117,395	85.84	4.55	0.31	93,589	85.72	430	0.04	115,286	8389	536	0.27	88,928

	2014				2015				2016			
Passenger Train Operating Company	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes	PPM(%)	CaSL(%)	SPAD Risk Rate	Celay Minutes
Arriva Trains Wales	92.39	285	1.11	242,615	92.88	2.53	0.60	235,581	9205	2.76	0.85	76,256
c2c	96.58	149	0.00	16,281	97.13	1.10	0.47	22,896	9583	1.53	0.00	10,898
Chiltern Railways	94.78	175	0.87	62,636	94.28	1.54	0.28	88,103	9521	0.94	0.00	27,931
CrossCountry	87.15	501	0.00	71,858	89.40	4.01	0.19	71,116	9054	3.75	0.21	18,898
East Midlands Trains	91.78	200	0.43	88,378	92.74	2.01	0.35	82,300	9327	2.10	0.44	24,328
First TransPennine Express	88.69	434	0.26	19,135	88.32	5.26	0.24	18,897	8904	5.51	0.19	4,633
Govia Thameslink Railway	84.10	457	0.00	672,567	81.55	5.40	0.56	908,203	8014	5.40	1.18	409,223
Great Western Railway	87.66	352	0.38	331,844	89.45	2.57	0.78	315,992	9124	2.53	0.63	98,199
Greater Anglia	89.63	266	0.94	172,542	89.60	2.76	0.36	209,905	9018	2.68	0.71	59,212
London Midland	87.46	300	0.66	208,169	87.84	2.92	0.89	217,461	8981	2.51	0.27	57,884
London Overground	95.53	171	0.82	39,981	94.20	2.17	0.51	58,088	9465	1.85	1.67	12,996
Merseyrail	95.69	187	0.98	39,859	95.43	1.90	0.72	41,140	9545	2.02	0.00	11,153
Northern	90.86	179	0.63	550,933	90.95	1.66	0.55	493,778	9178	1.69	0.21	141,127
ScotRail	91.44	199	0.55	317,353	90.34	2.58	0.58	312,319	9078	2.36	0.29	100,602
South West Trains	89.17	308	0.56	228,835	90.37	2.58	0.86	260,900	8922	3.04	0.85	80,324
Southeastern	88.00	324	1.00	302,550	88.46	3.18	0.95	347,590	8528	4.14	0.59	77,173
Virgin Trains West Coast	85.22	489	0.18	90,921	85.74	4.95	0.22	87,921	8605	4.41	0.00	21,401

Passenger Train Operating Company	2006 PPM	2006 CaSL	2006 SPAD Risk Rate	Celay Minutes PPM	2007 CaSL	2007 SPAD Risk Rate	Celay Minutes PPM	2008 CaSL	2008 SPAD Risk Rate	2008 Celay Minutes	2009 PPM	2009 CaSL	2009 SPAD Risk Rate	2009 Celay Minutes
Arriva Trains Wales	13	15	1	4	9	8	6	12	11	13	4	3	7	11
c2c	1	4	1	1	5	1	2	4	5	2	2	1	6	2
Chiltern Railways	2	1	1	2	1	5	1	1	6	4	3	2	4	5
CrossCountry	16	17	1	15	17	6	12	16	3	7	12	16	10	6
East Midlands Trains	15	13	1	14	14	4	15	13	13	8	7	8	3	7
First TransPennine Express	9	16	1	5	13	7	11	15	2	1	8	15	11	1
Govia Thameslink Railway	6	8	1	11	10	1	7	10	1	16	15	13	1	16
Great Western Railway	17	11	1	17	15	11	14	11	8	15	9	10	8	15
Greater Anglia	10	7	1	9	6	10	10	6	15	10	11	9	16	10
London Midland	14	10	1	12	11	16	16	14	9	9	16	14	13	9
London Overground	4	12	1	7	12	17	5	5	17	5	6	11	17	4
Merseyrail	3	9	1	3	8	14	3	8	14	3	1	4	14	3
Northern	12	5	1	13	7	9	13	9	10	17	10	5	12	17
ScotRail	7	3	1	8	3	12	9	7	7	12	13	7	5	13
South West Trains	5	6	1	6	2	13	4	2	12	11	5	6	9	12
Southeastern	8	2	1	10	4	15	8	3	16	14	14	12	15	14
Virgin Trains West Coast	11	14	1	16	16	3	17	17	4	6	17	17	2	8

Passenger Train Operating Company	2010				2011				2012				2013			
	PPM	CaSL	SPAD Risk Rate	Celay minutes	PPM	CaSL	SPAD Risk Rate	Celay Minutes	PPM	CaSL	SPAD Risk Rate	Celay minutes	PPM	CaSL	SPAD Risk Rate	Celay Minutes
Arriva Trains Wales	3	6	14	11	4	10	14	12	5	11	14	12	5	8	13	12
c2c	2	3	1	2	1	1	3	1	1	1	17	2	1	1	10	1
Chiltern Railways	4	1	13	5	7	4	7	8	4	2	4	6	4	2	3	5
CrossCountry	15	17	7	6	16	16	2	5	15	17	3	5	14	15	4	6
East Midlands Trains	7	7	5	7	5	5	6	6	6	7	13	7	6	10	6	8
First TransPennine Express	9	15	3	1	6	13	4	2	8	14	6	1	11	16	2	2
Govia Thameslink Railway	13	13	1	16	12	15	1	17	14	13	1	17	15	14	1	17
Great Western Railway	8	9	10	13	11	11	9	15	13	12	12	15	13	11	8	15
Greater Anglia	14	10	6	12	15	9	11	11	12	9	8	9	10	7	15	9
London Midland	11	8	8	9	13	12	8	9	16	15	10	10	16	13	9	10
London Overground	5	11	9	4	2	2	17	4	2	4	16	4	2	4	17	4
Merseyrail	1	4	17	3	3	7	16	3	3	10	9	3	3	3	16	3
Northern	10	5	12	17	9	3	10	16	11	5	7	16	9	5	12	16
ScotRail	12	12	11	15	14	14	13	13	7	3	5	13	7	6	7	13
South West Trains	6	2	15	10	8	6	12	10	9	6	11	11	8	9	14	11
Southeastern	16	14	16	14	10	8	15	14	10	8	15	14	12	12	11	14
Virgin Trains West Coast	17	16	4	8	17	17	5	7	17	16	2	8	17	17	5	7

	2014				2015				2016			
Passenger Train operating company	PPM	CaSL	SPAD Risk Rate	Celay Minutes	PPM	CaSL	SPAD Risk Rate	Celay Minutes	PPM	CaSL	SPAD Risk Rate	Celay Minutes
Arriva Trains Wales	5	9	17	12	5	7	12	11	6	11	15	11
c2c	1	1	1	1	1	1	7	2	1	2	1	2
Chiltern Railways	4	3	13	5	3	2	4	8	3	1	1	8
CrossCountry	15	17	1	6	12	14	1	5	10	13	6	5
East Midlands Trains	6	7	7	7	6	5	5	6	5	6	10	7
First TransPennine Express	11	14	5	2	14	16	3	1	14	17	5	1
Govia Thameslink Railway	17	15	1	17	17	17	10	17	17	16	16	17
Great Western Railway	13	13	6	15	11	8	14	14	8	9	12	14
Greater Anglia	9	8	14	9	10	11	6	9	11	10	13	10
London Midland	14	10	11	10	15	12	16	10	12	8	8	9
London Overground	3	2	12	4	4	6	8	4	4	4	17	4
Merseyrail	2	5	15	3	2	4	13	3	2	5	1	3
Northern	8	4	10	16	7	3	9	16	7	3	7	16
ScotRail	7	6	8	14	9	9	11	13	9	7	9	15
South West Trains	10	11	9	11	8	10	15	12	13	12	14	13
Southeastern	12	12	16	13	13	13	17	15	16	14	11	12
Virgin Trains West Coast	16	16	4	8	16	15	2	7	15	15	1	6

PPM percentage, CaSL on a lowest CaSL percentage, SPADs based on the lowest SPAD risk rate and delay minutes based on the lowest delay minutes for each year.

These rankings were then summed up and ranked again to produce Table 2. This was aimed at identifying the performance of each TOC as per the defined performance indicator over the 10 years' period.

To test the hypothesis, the ranked data were grouped into operational performance and safety performance to plot the correlation graph shown in Fig. 1. Using the Spearman's correlation statistical technique, safety and operational performance data are correlated to establish whether there is a relationship between the two variables.

The result shown in Fig. 1 illustrates a weak negative correlation between the two variables with an R^2 value of 0.05. That is, with a calculated p-value of 0.365 at 5% significance level, H_0 is accepted and H_1 is rejected; hence, in this analysis safety and operational performance are independent variables.

Furthermore, focusing on one high-level measure for safety and operational performance, SPAD risk rates and TOC-on-Self-delay minutes ranked data (as shown in Table 2) were plotted in the correlation graph shown in Fig. 2. The result from the graph however shows a weak positive correlation between the two variables with an R^2 value of 0.03. At 5% significance level, the calculated p-value is 0.508. That is, H_0 is again accepted and H_1 is rejected; hence, safety and operational performance are still found to be independent variables.

Table 2: TOCs total ranked performance for the period 2006–2016 (Source: Author's Construct, 2016).

TOTAL Ranked Performance for 2006–2016				
Passenger Train Operating Company	PPM	CaSL	SPAD	Delay Minutes
Arriva Trains Wales	60	101	126	57
c2c	14	24	53	8
Chiltern Railways	37	20	60	26
CrossCountry	152	175	42	80
East Midlands Trains	92	95	72	43
First TransPennine Express	106	164	45	45
Govia Thameslink Railway	144	144	35	135
Great Western Railway	134	120	92	120
Greater Anglia	121	92	108	84
London Midland	155	127	104	86
London Overground	44	73	144	30
Merseyrail	26	67	123	16
Northern	109	54	92	129
ScotRail	102	77	81	99
South West Trains	82	72	116	92
Southeastern	129	102	137	108
Virgin Trains West Coast	176	176	31	66

Ranks			
PPM	CaSL	SPAD	Delay Minutes
5	10	15	7
1	2	5	1
3	1	6	3
15	16	3	9
7	9	7	5
9	15	4	6
14	14	2	17
13	12	9	15
11	8	12	10
16	13	11	11
4	6	17	4
2	4	14	2
10	3	9	16
8	7	8	13
6	5	13	12
12	11	16	14
17	17	1	8

In this instance, looking at data at an aggregate level has led to the surprise finding of an absence of a relationship between the two variables. In order to establish whether there is a relationship between safety and operational performance, a less aggregate form of the data is tested. In addition, TOC-on-Self-delay minutes are normalized by train kilometres, and a correlation graph for the financial year 2015/2016 is plotted. This results in a weak statistical

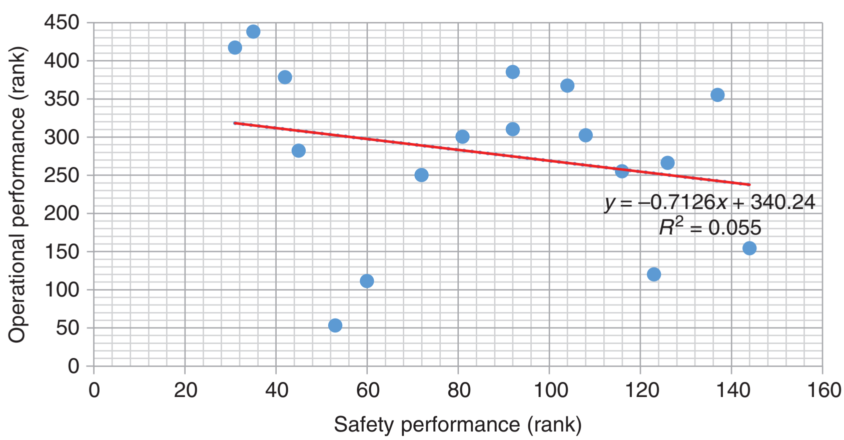

Figure 1: A scatter graph illustrating total ranked operational and safety performance of TOCs for the period 2006–2016 (Source: Author's Construct, 2016).

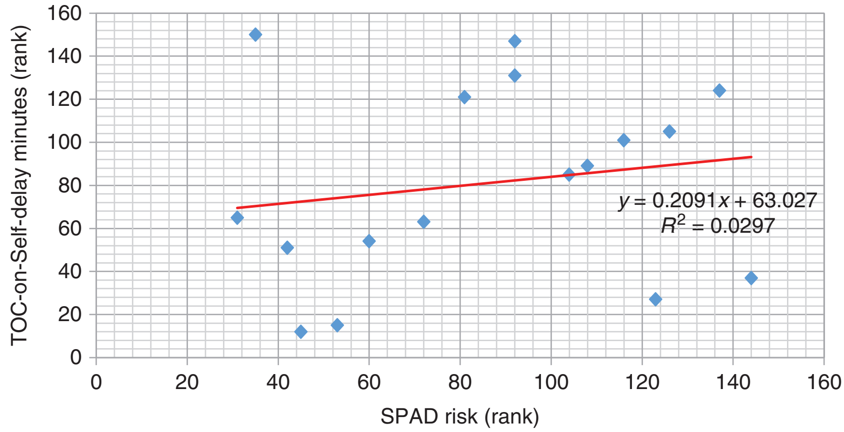

Figure 2: A scatter graph illustrating total ranked delay minutes and SPAD risk of TOCs for the period 2006–2016 (Source: Author's Construct, 2016).

relationship between safety and operational performance. Hence, with a calculated *p*-value of 0.46, H_0 is once again accepted at a 5% significant level.

A further iteration of the data was done using total delay minutes for the period 2015–2016 normalized by train kilometres and plotted against SPAD risk rate data of the same period. Here, the trend changes showing a stronger positive correlation between the two variables in comparison to the previous tests. Calculated R^2 as illustrated in Fig. 3 is 0.36. With a calculated *p*-value of 0.01 at 5% significance level, H_0 is rejected and H_1 on the other hand is accepted, hence, beginning to establish a positive association between safety and operational performance.

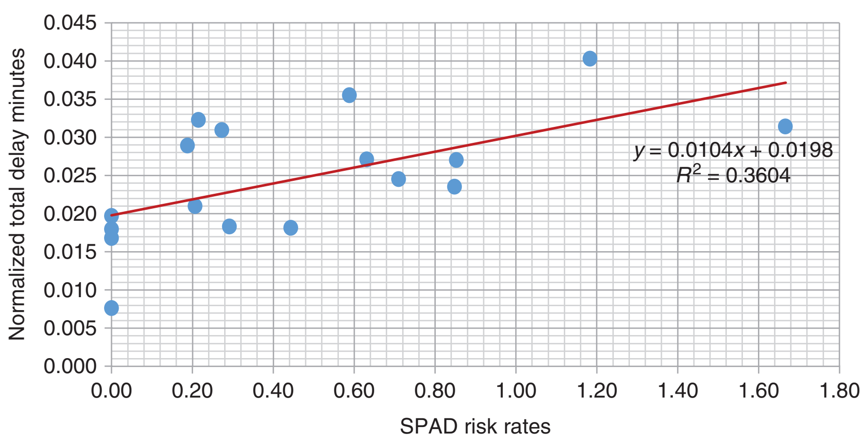

Figure 3: A scatter graph illustrating normalized total delay minutes and SPAD risk rate of TOCs for the period 2015/2016 (Source: Author's Construct, 2016).

Although the research initially focused on TOC-on-Self-delay minutes as a means of concentrating on parameters within the managerial control of TOCs, it is noted that Network Rail-on-TOC delay minutes (contributing 61% of 2015/2016 total delays per available ORR data) are related to safety performance and in effect influence TOCs operational performance. That is, there is a strong positive correlation between normalized Network Rail-on-TOC delay minutes and SPAD risk rate as illustrated in Fig. 4. With a calculated *p*-value of 0.01 at 5% significance level, H_0 is also rejected and H_1 on the other hand is accepted, hence, establishing a positive association between safety and operational performance.

By adapting a benchmarking methodology of ranking safety and operational performance of TOCs, this helps identify best and worst performers of TOCs in each of the performance areas. From the graph illustrated in Fig. 5, c2c (ranked first in both) and Merseyrail (first in

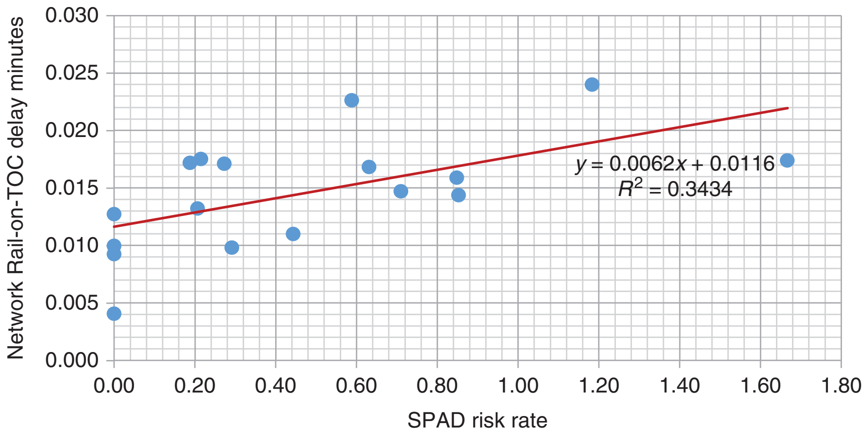

Figure 4: A scatter graph illustrating normalized Network Rail-on-TOC delay minutes and SPAD risk rate of TOCs for the period 2015/2016 (Source: Author's Construct, 2017).

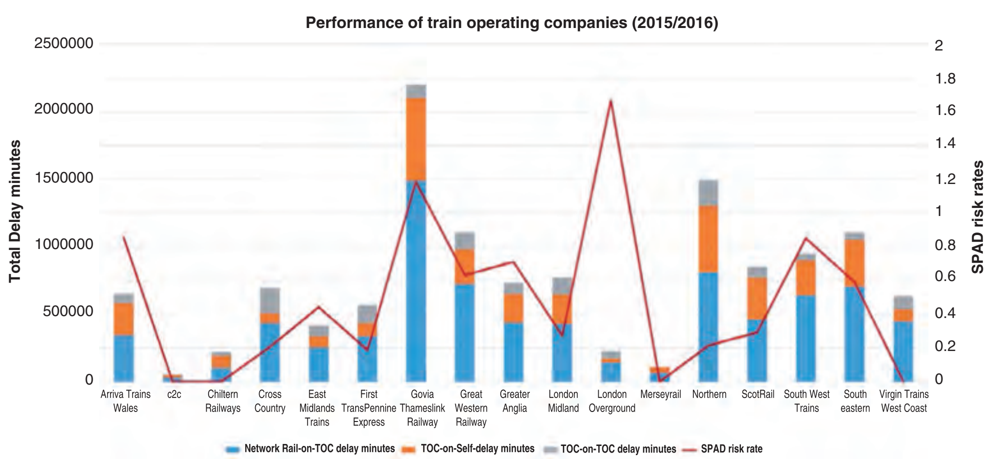

Figure 5: A combined line and stacked bar graph showing 2015/2016 safety and operational performance of TOCs, respectively (Source: Author's Construct, 2017).

safety and second in operational performance) are identified as TOCs with the best performance for both safety and operational performance. Govia Thameslinks Railways is noted to have the second worst performance in both safety (16th) and operational (17th) performance which ascertains the point that Network Rail-on-TOC delay minutes have an influence on TOCs performance as Govia Thameslink Railways experiences the most Network Rail-related delays.

The most interesting performance observed from the graph in Fig. 5 is that of London Overground. With total delay minutes of 772,474 (4th), it experiences the worst safety performance (17th) among the group which could be resulting from the circumstances of its operation. This suggests that there are factors peculiar to influencing only the safety performance of TOCs and alternatively influencing only operational performance or both safety and operational performance of TOCs. A variety of influencing factors may include service type, number of red signals approached on service route, driver communication and training, track and fleet maintenance among others.

In this light, exploring the various underlying factors influencing the safety and operational performance of TOCs while identifying best practices such as safety culture, efficient management of train timetable scheduling among others with the help of a benchmarking methodology is the next phase of this research. At this stage, a much more detailed correlation may be developed with a variety of hypothesis developed from the various best practices identified which may be mapped as one variable and safety performance as another variable.

4 LESSONS LEARNT AND FURTHER STUDIES

To further explain the differences in performance and provide an in-depth understanding of the relationship between safety and operational performance, other high-level measures need to be considered. For instance, aside SPAD risk rates, other indicators such as infrastructure failures, infrastructure operations, train operations and failures and/or level crossings in the SRM need to be considered and explored. Also, the study seeks to further explore the relationship between safety and operational performance by acquiring a more detailed data from RSSB representing daily SPAD incidents occurring between October 2015 and March 2016 to be correlated with daily PPM values within the same period. This is aimed at establishing a stronger statistical relationship between the two variables in order to get a better understanding of the data and relationship between safety and performance.

Moreover, site visits and observation of operational and safety management practices within some selected TOCs are considered to be useful in the benchmarking process for comparison and identification of best practices. This will be useful in recommending certain managerial practices to improve safety and operational performance in TOCs with low performance as well as the rail industry of developing economies who seek to run an efficient, reliable and safe rail transport system. Publication and analysis of data relating to key performance indicators (for both safety and operational performance) is itself a useful tool that may have helped improve performance in the rail industry and may be a lesson that can be suitably translated into developing countries.

5 OTHER OBSERVATIONS

However, in the absence of identified best practices within TOCs at this stage of research, the current features of Britain's rail industry developed over the years through the various decisions and investments made by government and industry could be considered by developing countries in improving their railways. Discussed below are two main observations for developing countries from the view point of this research.

First, the institution of a regulatory body such as ORR could ensure the improvement of safety and performance of the railways. Known to be among the safest railway networks in the world, Britain's railway highlights the possibility that the institution of a regulatory body to ensure safety, value and performance of railways could improve safety and operational performance. A similar body is South Africa's RSR which ensures the improvement of rail safety in the country. By general consensus, South Africa is known to have the most functional railway network in Africa. Developing a hypothesis to test the effect of the presence of regulatory bodies on the performance of rail industries could be useful in the recommendation stage of this research.

In addition, one of the most important observations is the development of a database for the recording and reporting of incidents on the network for which this research may have proved a lot more difficult that it currently is. As seen in the British railway industry, RSSB developed and managed a SMIS to provide a safety reporting system through which research, analysis, standards and insight are used to help the industry deliver a safer, more reliable and sustainable rail system. Rail industries in developing countries do not necessarily need a complex system like SMIS but having a well-defined institution or process to cater for the reporting and management of all forms of incident data on the network could be a useful practice for the industry. Collecting the data is certainly not enough, however, making meaningful analysis in aid of improving performance and influencing decisions in the development of the rail industry and the country as a whole.

6 CONCLUSION

In conclusion, it seems that various decisions and investments made by industry and government over the years to improve railway safety in Britain have in one way or another impacted or influenced operational performance in the industry. The absence of strong statistical evidence at this point of the research does not imply that there is no significant relationship between safety and operational performance as the data were in aggregate form. However, segregating the data with focus on specific events and its impact on both safety and operational performance is the next step and more likely to provide interesting results. This is shown in the 2015–2016 correlation results discussed earlier. It is also evident that the railway system is a very complex one, and when high-level performance indicators that may be expected to correlate are found not to do so shows that a 'deeper dive' is needed into the relationships to test the original hypothesis. This itself is a lesson for all developing railways for which the publication and analysis of data relating to key performance indicators, in both operation and safety, can be an aid in improving performance of the rail industry

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SUSTAINABLE DEVELOPMENT AND PLANNING 2017

OVERVIEW

The 9th International Conference on Sustainable Development and Planning (SDP) 2017 recently took place at the University of the West of England (UWE) Bristol. The conference was organised by the Wessex Institute (WIT) and was co-sponsored by WIT and the UWE, the latter represented by Professor James Longhurst.

The conference follows the success of previous meetings which started in Skiathos, Greece (2003), and continued in Bologna (2005); Algarve (2007); Cyprus (2009); the New Forest, UK, home of the Wessex Institute (2011); Kos, Greece (2013); Istanbul, Turkey (2015); and Penang, Malaysia (2016).

The conference brought together scientists and other stakeholders from across the globe to discuss the latest scientific ideas in the field. The meeting also highlighted developments in managerial strategies and associated tools for policy and decision makers.

OPENING THE CONFERENCE

Professor Longhurst welcomed the delegates and expressed the hope that they would find the opportunity to visit Bristol, a vibrant and historical city with many sights of interest but also with a strong commitment to sustainable growth culminating with being nominated the “Green Capital of Europe” for 2015. Bristol, a city in the process of rapid development, was a most appropriate location for SDP 2017.

He then invited Dr Stavros Syngellakis, professor at WIT and a member of its Board of Directors to open the Conference on behalf of Professor Brebbia, who was unable to be present due to health reasons. Stavros started by thanking the UWE authorities for hosting the meeting.

Stavros then explained the aims of WIT, i.e. providing a medium for knowledge transfer at an international level. This objective is achieved through a series of activities, i.e. meetings, including conferences; research at postdoctoral level; publications; and consultation services for industry.

WIT software codes, based on advanced computational methods, are widely used in aerospace, energy and mechanical engineering, amongst others. WIT’s commitment in this regard led to setting up a special office in Boston to serve the USA industry.

SDP 2017 is part of the 25 or so international conferences that WIT organises every year. They cover a wide range of interests focussed on the importance of promoting interdisciplinary exchanges.

Delegates at the conference

Stavros finished his introductory remarks by stressing the success of SDP17 in terms of the number of participants and the quality of the papers published in the conference volume. The volume is part of WIT Transactions on Ecology and the Environment and published in digital as well as hard cover formats. All papers are also archived in the eLibrary of the Institute (www.witpress.com/elibrary) where they are easily accessible to the international community.

CONFERENCE TOPICS

The Conference sessions had the following headings:

- Sustainability and the built environment
- Cultural heritage
- Case studies
- Risk management
- Education and training
- Planning for equality
- Quality of life
- Sustainability and the built environment
- Climate change
- Sustainable tourism
- Sustainable solutions in emerging countries

- Energy efficiency
- Governance
- Environmental planning
- Transportation issues and mobility
- Waste water

INVITED PRESENTATIONS

The meeting was enhanced by a series of invited presentations, as follows:

- "Towards a sustainable university", **Jim Longhurst,** University of the West of England, UK.
- "Sustainable tourism and destination management: The Greek Island of Poros", **Dimitris Prokopiou**, University of Piraeus, Greece.
- "Sustainability, curriculum and academics in higher education", **Georgina Gough**, University of the West of England, UK.
- "Greener households? The effectiveness of smart meters in reducing energy consumption levels in the DACH region", **Andrea Hoeltl**, Donau-Universität Krems, Austria.
- "Raising standards: developing a benchmark for green infrastructures", **Nicholas Smith**, University of the West of England, UK.
- "The challenges posed by problem soils on performance of road pavements", **Richard Mwaipungu**, Sansutwa Simtali Ltd, Tanzania.
- "Insights and issues into the uptake and development of advanced anaerobic digestion within the UK water industry", **Colin Booth**, University of the West of England, UK.

CONFERENCE PROCEEDINGS

The Conference, as all WIT meetings, was most friendly and provided an excellent atmosphere for the exchange of opinions and discussions.

The many papers presented at the meeting did not allow for any special group excursions to be arranged but many of the delegates were able to visit the amenities in the Bristol region, rich in history and cultural events.

The Conference banquet took place at Bordeaux Quay by the river in a restaurant belonging to the Sustainable Restaurant Association. The excellent atmosphere and the choice of wines made this a unique occasion.

The next Conference in the series will be held from 4–6 September 2018 in Siena Italy.

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