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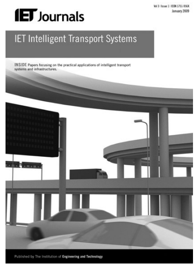

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Method for quantitative valuation of road freight transport telematic services

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Abstract: This study describes transport telematic services (TTSs) for road-based heavy goods vehicle (HGV) transport and suggests a method for assessing the societal value of different TTSs. For decision making related to the selection of services to promote by potential investors, for example, governmental organisations and service providers, quantified service value can simplify the decision process by enabling comparison between TTSs. Moreover, these values can serve as inputs to quantitative analysis of service architectural system designs. The authors suggest a method for assessing the societal values of TTSs using potential saving indicators (PSIs), estimated in the context of Swedish HGV freight transport. To illustrate the proposed method, 32 services are analysed, and their societal values were quantified and compared for the Swedish HGV market. Results based on estimated values of PSIs and potential percentage savings indicate the following HGV-based TTSs to be of high societal potential: transport resource optimisation, dynamic traffic information, navigation, road hindrance warning, theft alarm and recovery, accident warning information, intelligent speed adaptation, eCall, en-route driver information, transport order handling, road user charging and sensitive goods monitoring.

1 Introduction

Although there is an increasing deployment of services that support private, non-commercial road users (drivers and passengers), there are few existing services today that meet the needs of heavy goods vehicle (HGV) transport. Although HGVs account for less than 5% of the overall vehicle stock in Europe, they contribute to more than 20% of the mileage driven [1]. Notwithstanding the low numbers, HGV transport has high impacts on society for example, accidents. Therefore impact assessment for cars and HGVs should be performed separately [1]. Telematic systems have the potential to significantly improve road freight transport by reducing negative societal effects like emissions, congestion and accidents. This article describes transport telematic services (TTSs) for road-based HGV transport, most of which were identified in the Mobile IT project [2]. Effects of TTSs that may result in modal shift and hence effective utilisation of the entire transport system have not been considered, but the method suggested can also be applied to study such effects. Also, costs associated with both the deployment and operations of TTSs (infrastructure and maintenance) are intentionally left out in order to focus on assessing their potential societal value. TTSs with a potential connection to an anticipated Swedish road user charging (RUC) system were identified in the previous study [3]. A framework was developed [4, 5] to analyse TTSs. Results of the current study can facilitate quantitative analysis of TTSs, for example, optimisation and simulation.

Different TTSs address various issues associated with freight transport, such as emissions, accidents and infrastructure maintenance. We use criteria established in previous studies [4, 5] to characterise TTSs [3]. The purpose is to develop a systematic approach for quantifying the societal values (valuation) of TTSs. A TTS can be specified following a range of general to specific dimensions, that is, motivation, user domain, users, functionalities, value and quality of service (QoS) [5]. The value of a TTS is assessed by the extent to which each TTS can reduce the cost of potential saving indicators (PSIs), for example, emissions, accidents and infrastructure maintenance. In addition to providing decision support, quantitative values can increase public acceptance of TTSs. Moreover, quantification of TTSs contributes towards assessing benefits of different telematic system design alternatives or platforms. Generic level analysis can enable comparing different TTSs and support decision making related to the selection of services to be promoted by potential investors, for example, governmental organisations and service providers.

The existing methods take into account both costs and societal value (positive benefit) of various TTSs from a cost benefit perspective with no consideration for dependencies between the positive benefits. Cost assessments are facilitated by the connection to different technologies and quantification of equipment for installation and maintenance

[6]. However, estimating societal value is challenging for several reasons: unknown penetration rates, lack of quantitative models, lack of operational data and so on Researchers suggest methods of service valuation based on system performance quality (Grönroos approach) [7] and emphasise the use of a risk-oriented approach rather than human capital approach, thus suggesting that the societal value of TTSs may be seen in terms of their ability to minimise risks [8]. The current study identifies and assesses the full potential (assuming a 100% penetration [8, 9]) of TTSs based on PSIs.

To achieve the above goal, a generic quantitative method is proposed to assess the values of different TTSs. The main advantage of a generic assessment approach is for identifying efficient TTSs for deployment on system platforms based on their functional characteristics [2, 10]. The approach proposed can be seen as building on project work related to system platforms carried out in Sweden and Europe, such as the Mobile Networks [11], Mobile IT [2], HeavyRoute [12], eIMPACT [6], SeISS [1] and so on. Societal costs of nine PSIs related to HGV transport in Sweden are assessed. PSIs are then used to calculate societal values of each TTS based on the percentage estimate of how each TTS can marginally reduce the societal costs of each PSI. With this approach the potential of any mix of TTSs can be estimated when the functions are combined to address different societal issues. Section 2 presents a short review of work related to the valuation of services, Section 3 proposes assessment criteria for valuating TTS, Section 4 presents PSIs, Section 5 discusses the different services considered in the study, whereas Sections 6 and 7 present the results, conclusions and discussions, followed by acknowledgements and references.

2 Service valuation: related approaches

Generally, services can be valued from two major perspectives, both connected to the service quality. On the one hand, value is based on subjective user perception (Parasuraman SERVQUAL method) [13], whereby a user of a service provides subjective information about how much a service is worth to them depending on the utility derived from the service. On the other hand, value is based on what a service can achieve as a result of its functionalities and performance, the so-called Grönroos approach [7]. Both these methods have been widely used for studying the QoS generating value for business services in a customer relations context. Such services differ from TTSs in many ways, for instance, TTSs are highly dependent on and can be improved through system performance [14], whereas customer relation services are dominated by the process of service delivery [13].

Studies suggest different approaches for evaluating the impact of ITS services [1, 15, 16]. Many EU projects focus on cost and benefits of technologies for TTSs such as CHAUFFEUR, DIATS, STARDUST, eIMPACT, ICSS [6, 8, 17, 18] and so on. The suggested impact areas include: driver and vehicle behaviour, mobility, traffic flow and efficiency, traffic safety, environment and socio-economics [19]. The current study focuses on potential impact areas for freight transport that can be quantified, for example, emissions, travel time. Empirical data from laboratory measurements (and real-world field operational tests), simulation and statistical analysis provide important approaches used for ITS socio-economic impact assessment [1]. The foremost statistical methods are cost benefit analysis and multi-criteria analysis [19]. Analytic hierarchy process models, portfolio and stakeholder analyses have also been used [6, 16]. Most traditional transport evaluation methods are seen to be limited in capturing complexities involved in the evaluation of TTSs and, hence, new methods need to be developed [7, 16]. From a societal perspective, a performance-based (capability to reduce PSIs) service valuation can be helpful in assessing the societal value of TTSs. Such an evaluation may reduce the subjectivity associated with user perception and concentrate on identifying and evaluating performance attributes of interest in relation to the intended effects, hence providing a better interface between the service and its expected outcome, based upon which the service can be redesigned and improved.

There are a number of measures used in investment analysis, for instance, net present value (NPV) (discounting payments to present times) and return on investment measure, that is, what is the gain (or loss) in relation to invested capital. We aim for an approximation of the yearly positive value. However, we allow for compensation in case one service takes a significantly longer time to achieve positive effects than another by discounting (by the number of years it takes to materialise), hence the associated yearly value is computed as

$$\frac{V}{(1+R)^T} \tag{1}$$

where V is the estimated societal value of the TTS, R denotes the interest rate and T the number of years it takes for the application to start producing some positive benefit. Equation (1) is based on the assumption that once a TTS starts to generate value, such a value remains constant over the years. This assumption then allows us to use the value generated by a service in the first year in comparison with other services. The time component of (1) is the year when this value begins and may be different for different services. The value of a service may vary from year to year, in which case the NPV should be considered. For the purpose of this study, we simplify the NPV by limiting it only to an average expected value when a TTS generates value. Similar approaches to NPV have been used for assessing, analysing and prioritising transport investment projects (including ITS) for governments [20].

3 A set of criteria for assessing TTS

A systematic analysis for TTSs and their potential economic value requires some criterion or criteria because the impacts of TTSs are seen in a number of diverse indicators. A complete specification that will take into account TTS benefits will need to include dimensions such as technology costs, functionality and QoS components for each TTS. The societal value of each TTS is the sum total of its percentage reduction of all PSIs (Section 4) with the assumption that a 100% service penetration level is attained. Variation in penetration level is disregarded in order to assess and compare the full potential of each TTS. Therefore, instead of differences in penetration levels, the proposed model has considered estimates of the decrease in marginal benefits when TTSs derive their value from common PSIs. Let us consider the following notation:

S: Set of services ($D \subseteq S$)
P: Set of PSIs (Section 4)

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$0 \le T_i$, $i \in S$: Number of years to start to generate value
$0 < \varepsilon$: Discounted interest rate
$0 \le P_k$, $k \in P$: Value (societal costs) of PSI
$0 \le \alpha_{ik} \le 1 i \in S$, $k \in P$: Potential percentage savings
$0 \le V^*_{i\hat{i}}$ i, $\hat{i} \in S$: Pairwise value assessment considering dependencies between TTSs

We now consider TTS value where the TTSs are considered independent of any similar TTSs addressing a common PSI, V_i, $i \in S$ based on (1) to be given by

$$V_i = \frac{1}{(1+\varepsilon)^{T_i}} \sum_{k \in P} \alpha_{ik} P_k, \quad i \in S \tag{2}$$

then the value for two TTSs $(i, \hat{i})$ can be given by

$$V^*_{i\hat{i}} = \frac{1}{(1+\varepsilon)^{T_{i\hat{i}}}} \sum_{k \in P} P_k(\alpha_{ik} + \alpha_{\hat{i}k} - \alpha_{ik}\alpha_{\hat{i}k}) \tag{3}$$

$$V^*_{i\hat{i}} = V_i + V_{\hat{i}} - \frac{1}{(1+\varepsilon)^{T_{i\hat{i}}}} \sum_{k \in P} P_k \alpha_{ik}\alpha_{\hat{i}k} \tag{4}$$

where $T_{i\hat{i}}$ denotes the average time for services i and $\hat{i}$. From the above, the last term of (4) determines the pairwise dependency between any two services i, $\hat{i} \in S$ whose values are obtained as in (1). This is due to the expected decrease in marginal benefits of two services that address a common PSI. Equation (4) can estimate dependencies between two TTSs (pairwise) for a given number of PSIs. To estimate the dependencies for a set of TTSs (D) with $|D| > 2$, it is necessary to consider a generalised form of (4) as

$$V^*_D = \frac{1}{(1+\varepsilon)^{T_D}} \sum_{k \in P} P_k \left[\left[\sum_{d \subseteq D} (-1)^{|d|+1} \right] \prod_{i \in d} \alpha_{ik} \right] \tag{5}$$

where $T_D = \sum_{i \in D} T_i / D$ and $\sum_{d \subseteq D}$ denotes the summation of all subsets of S (including D).

The value of T_D is an approximation since each TTS will have a different discount factor. The savings assessment for each TTS (corresponding to $0 \le \alpha_{ik} \le 1$ in the above equations) takes into account results reported from various TTSs implemented around the world. There have been many field operational tests for different applications (as in [21, 22]), but most results are not reported in concrete terms that could directly be transferred to other studies. Most of the applications achieving these savings are implemented for road transport including both commercial vehicle transport and private cars. In addition, the degree to which each transport system is improved by the TTSs depends on the prevailing conditions of the transport system before the service was implemented.

4 PSI calculations for valuation of TTS

We have chosen to assess the values of services by connecting the effects of a service to a set of areas (attributes) where, potentially, resources can be saved or some costs reduced, thereby generating societal value. High-level societal attributes related to fuel, vehicles and so on contribute to different types of transport costs [23] and, hence, incur a loss to society. We suggest the following general PSIs in the next subsections.

4.1 Fuel costs

This PSI measures the costs of fuel excluding value-added tax and constitutes a large share of the HGV operational costs [24]. According to the current fuel pricing scheme in Sweden, this cost also includes external costs of carbon dioxide (CO_2) emissions. Therefore in calculating other externalities we have exempted CO_2 emissions costs. Fuel consumption depends on factors such as weather, road topology, tyre pressure, total vehicle weight, engine type and speed, making it difficult to estimate consumption per vehicle kilometre (VKM). Different studies have suggested the following values: 0.43l L/VKM [25], 0.52 L/VKM [24] and 0.5 L/VKM [26]. The Swedish Road Hauler Association estimate an average fuel cost of 0.287€/VKM [24]. Suppose that 0.287€/VKM is the average cost of fuel consumption for an average loaded HGV (which was 15.2 tons in 2008) and that 66 846 Swedish registered HGVs with a total weight of at least 3.5 tons had a total mileage of 2900 million KM on Swedish roads in 2008 [27], then total cost of fuel consumed in 2008 is 0.287×2900 million € = 832 million €.

4.2 Distance-based costs

This PSI is estimated based on vehicle depreciation and maintenance. A study suggests the variable costs of road transport to be 0.465€/VKM [24]. This cost includes fuel (0.287€/VKM), vehicle depreciation (0.421€/VKM), tyres (0.379€/VKM) and vehicle maintenance including servicing (0.098€/VKM). The total mileage of 2900 million KM in 2008 will correspond to a KM cost (excluding fuel) = (0.465−0.287)€/VKM = 0.1777€/KM resulting in a total distance-based cost of 2900×0.1777 million € = 515 million €.

4.3 Time-based costs

This involves driver and vehicle's time-based costs including activities such as loading and unloading. The main cost is the driver's salary estimated at 17.5€/h including retirement and insurance benefits [24]. Congestion also contributes to time-based costs. In 2008, the average speed for HGVs in Sweden was estimated at 70 KM/h [27], which could be lower if loading and unloading time are taken into consideration, and hence the number of hours will be much more than suggested below. Time-based costs for the vehicle have been ignored. Hence, the corresponding time is = Distance/Speed = 2900 million KM/(70 KM/h) resulting in total driver costs = (2900 million KM)/(70 KM/h) $\times$ 17.5 € = 725 million €.

4.4 Transport administration

Transport administration has been calculated to cost 7.5€ per driver hour [24] in Sweden. Suppose this value is an average cost for all hauler companies, the total costs resulting from this will depend on the total number of hours driven, which is given by average speed/total distance = 2900 million KM/(70 KM/h). With cost per hour = 7.5 €, we have a total cost = (2900 million KM)/(70 KM/h) $\times$ 7.5 = 311 million €.

4.5 Accidents

Costs of accidents are considered to include severely and slightly injured persons in road traffic that were hospitalised or died as a result. HGV-related road accidents in Sweden during 2009 resulted in 87 dead and 1953 with severe and serious injuries [28]. A total of 9500 people were hospitalised for at least one day as a result of road traffic accidents in 2008, costing the hospitals 69 million € in total [28, 29]. This is underestimated because the secondary effects of such accidents such as job loss to the individual involved are not taken into consideration. Assuming a similar average cost structure in 2009 as in 2008 with statistical life as 2.15 million € [30], that is, (69 million €)/9500, the total costs of injury (HGV only) = (69 million €)/9500 × 1953 = 14 million € and cost of deaths = 2.15 × 87 million € = 187 million € resulting in a total cost of all accidents = 201 million €.

4.6 Infrastructure maintenance costs

This PSI attempts to assess the costs associated with infrastructure maintenance such as roads, bridges and tunnels. This is usually considered as the cost of wear and tear and has been estimated to be 1.15 €/100 VKM for private cars with a depreciation period of 50 years [31]. We approximate cost for the HGVs to be 2.3 €/100 VKM roughly equal to the earlier proposed values [31, 32]. Hence, for total distance 2 900 million KM in 2008 and cost of maintenance per VKM = 0.023 €, we get a total cost = 2 900 million × 0.023 = 67 million € which is 17% of the total road maintenance cost reported by the Swedish road administration (SRA) (398 million €) in 2008 [32].

4.7 Noise and related external costs

This PSI estimates the societal costs related to external effects excluding CO_2 emissions (considered to be included in fuel costs in Sweden) for example, particle emissions estimated at 0.033and 0.110€/VKM (in urban areas and cities, respectively, [33] for trucks weighing at least 3.5 tons) and noise estimated at 0.0398€/VKM [34]. Hence, with the total driven KM for all vehicles on city roads = 22 000 million KM and total driven KM for all vehicles on all roads = 52 000 million KM, we estimate the ratio of driven KM on city roads to total driven KM on all roads in 2008 = 22/52 = 0.42. Using this percentage for the HGVs we get 0.42 × 2 900 million = 1 230 million KM. Thus, HGV external environmental costs excluding CO_2 in cities = 1230 million KM × 0.110€/VKM = 135 million €. Driven distance in areas other than city roads = (2 900-1 230) million KM = 1 670 million KM, resulting in emission costs of 1 670 million × 0.033 € = 55 million €. With the total cost of noise = 2 900 million × 0.039 8 €/VKM = 115 million €, we get the total costs of noise and related external costs = 135 million € + 55 million € + 115 million € = 306 million € (approximately).

4.8 Building of new infrastructure

This PSI is aimed at estimating the costs of infrastructure expansion and related external costs, for example, population displacement. TTSs can potentially influence the utilisation of road infrastructure and hence other resources such that physical expansion of infrastructure is minimised. The SRA calculates the building of new road infrastructure and associated annual costs to be 913 million € and 982.6 million € for 2007 and 2008, respectively [32]. Thus, we can approximate an annual cost of building new roads to be about 970.5 million € per year. With a utilisation level for the HGV of 42% we calculate the corresponding demand on new infrastructure for the HGVs as 0.42 × 970.5 million € = 408 million €.

4.9 Cost of missing and delayed goods

Theft cases involving HGVs reported in Sweden went down from 2377 cases in 2007 to 2140 cases in 2008 [35] and related costs were estimated for HGV in 2008 at 243.5 million € in Sweden [36], including secondary effects such as the value of goods and possible costs as results of business obstructions. Cost of crimes in 2008 in Sweden was estimated at over 100 million €, allocating a theft value of 47 million € and incremental costs of 53.4 million €, along with an additional 140 million € that accounted for customer aspects and marketing costs. Thus, we approximate total cost of HGV-related theft at 240 million €, noting that the study did not cover all of Sweden. Furthermore, an HGV can accumulate about 100 short delays of upto 15 min each which add costs [37]. Although most of these are associated with traffic conditions (congestion), about 20–30% are assessed to be related to other aspects, such as weather conditions, accounting for an estimated cost of 3.5 million € excluding loading and unloading costs [37]. Therefore we assess a total approximate cost associated to theft and delays = 244 million € (240 million € + 3.5 million €).

The different PSIs calculated above can be summarised in a diagram as shown in Fig. 1.

In a related work that uses simulation to calculate HGV cost distribution for the HeavyRoute project [38], we observe that there are significant differences in time-based costs of 45% for the HeavyRoute project compared with the 23% estimate in this study. This is partly due to the distribution of cost functions as this study considered the costs of infrastructure expansion, transport administration and missing and delayed goods, which were not separately considered in HeavyRoute. On the other hand, climate cost is considered as a separate cost function by HeavyRoute, which we considered as fuel (CO_2) costs.

5 Potential road freight TTS

We discuss TTSs in the context of vehicles, goods, drivers, owners, infrastructure and other stakeholders that in one way or another contribute to road transport operations, with some already existing and others proposed within the Mobile IT project. Particular attention is given to similar existing systems tested and any results obtained. Each of the suggested TTSs given below can in turn be composed of specific sub-services.

Accident warning information (AWI): AWI provides accident information to nearby vehicles to enable users to reduce the effect of accidents, for example, queue build up, chain accidents, fire, rear end collisions (considered to make up to 13.5% of accidents in Sweden in 1999 [39]). Freeway incident warning systems have shown that travel times could be reduced by 21% [40] and fuel and delays by up to 3 and 7%, respectively [41].

Advanced driver logs (ADL)*:* ADL records various time-based activities for HGV drivers and helps the driver to avoid driving under the influence of external factors such as alcohol, which has been shown to account for up to 16% of driver accidents in 2008 [38].

Driver planning (DP): DP improves driver performance through planning (optimisation) by considering factors such

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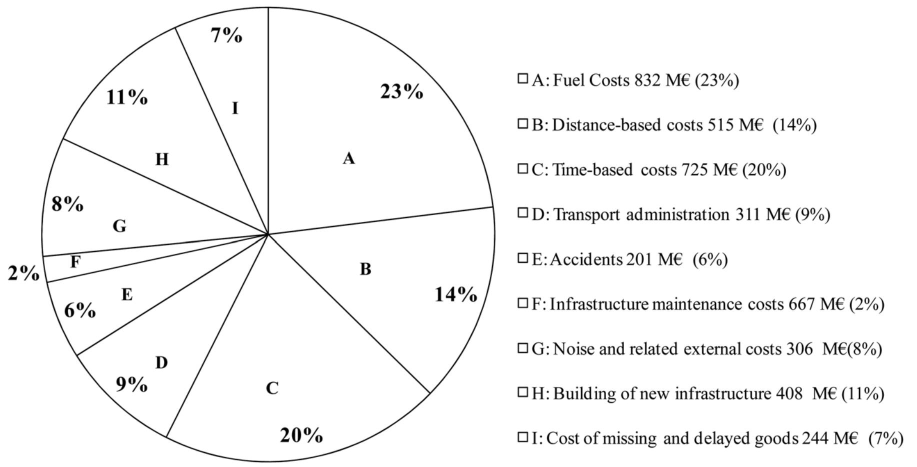

Fig. 1 *Results of cost distribution for PSIs as a relative percentage*

as time of day, route, vehicle, product, season and so on that suit individual driver preferences.

Dynamic traffic information (DTI)*:* DTI service provides real-time traffic information that contributes to reducing costs related to delays, congestion and so on [42]. If accidents do not lead to delays, then information about such accidents is obtained through AWI.

eCall (EC)*:* EC reduces the time taken to locate and rescue victims of an accident as well as the vehicle and its contents. It reduces the total cost related to accidents by preventing deaths and reducing accident severity and waiting time because of accidents for other vehicles on the road. Trials in Stockholm suggest the accident cost reduction potential to be between 5and 15% [43].

Emission testing and mitigation (ETM): ETM measures environmental performance to support policy making.

En-route driver information (EDI): EDI provides trip specific information to load/unload goods including communication with back office.

Estimated time of arrival (ETA): ETA monitors the current traffic situation and evaluates arrival time dynamically. Reliability inaccuracies may cost up to 2.2€ per vehicle trip [15].

Freight mobility (FM): FM communicates real-time freight data between drivers, dispatchers, goods owners and so on.

Geo-fencing (GEO): GEO provides control support for areas of interest such as corridors, military areas, accident areas, parking areas, tunnels and so on without using any physical barriers.

Goods identification (GI): GI improves goods handling (loading/unloading, declaration etc.) using contactless identification.

Infrastructure repair and maintenance (IRM): Information about IRM provides real-time information on the status and maintenance history of infrastructure, that is, similar to preventive maintenance that has been considered to potentially reduce maintenance costs by 25% [25].

Extra-large (XXL): Information on the transportation of extra-large cargo supports drivers, public authorities and the back office in the following legal obligations for example, desired route and monitoring.

Information on truck parking (ITP): ITP provides parking-related information in real-time to drivers and facility owners. Similar systems have been reported with about 1–2% reduction in parking location time [44] and 9% in travel time [45].

Intelligent speed adaptation (ISA): ISA provides dynamic information about the current speed limit that can lead to a reduction in accidents and fuel consumption, with the trial results in Sweden showing an estimated reduction of 20 to 30%, if all cars were equipped with an ISA system [21].

Navigation (NAV): NAV through a route network provides HGV-relevant information that can reduce delays. NAV has contributed to reducing queue times and delays for previously unknown destinations between 5 and 20% [9]. NAV focuses on unknown destinations, DTI focuses on floating car information with no advanced navigation capabilities.

On-board driver monitoring (ODM): ODM monitors and reports (to the authorised agents e.g. traffic and transport managers, including rescue units) driver conditions in real-time, for example, health. Accidents related to driver fatigue have been estimated at 15% in Sweden [28].

On-board safety and security monitoring (OSM): OSM helps the driver to constantly monitor the vehicle and its contents without manual checks, for example, temperature for refrigerated products.

Pay as you drive (PYD): PYD provides location-related information to insurance companies to help reward drivers according to risk attitudes and exposure and reinforces good driving [46]. Studies show a reduction of 10% in mileage and fuel consumption and 15% in total crashes [47].

Real time track and trace of goods (RTT): RTT provides information such as speed, location and status of goods to goods owners, transport managers and so on that can enable tracking of such goods if necessary.

Remote declaration (RED): RED enables declaration of information to be transferred electronically at gates, control stations, loading/unloading stations and so on to reduce delays.

Remote monitoring (RM): RM minimises costs related to vehicle breakdown through preventive maintenance.

Road hindrance warning (RHW): RHW provides information related to hindrances in real-time and possible suggestions to avoid queues.

RUC: RUC (electronic toll collection) collects charges related to the use of road infrastructure based on location, time, road type and vehicle type similar to most systems anticipated in Europe [48]. Trials have led to a reduction in traffic growth (5%), vehicle trips (8%) and empty trips (20%) [49]. Congestion control schemes in Stockholm (related to but different from RUC) have led to reduced traffic (10 to 15%), shorter queue time (30 to 50%), lower emissions (2.5%) and fewer accidents (5 to 10%), [50] as well as 16% less congestion [51].

Route guidance (RG): RG provides information relevant to specific corridors related to, for instance, zebra crossings, school children and so on and also helps the infrastructure owners influence the use of a given route. Studies have shown a reduction in travel times under average congestion conditions for all vehicles [52]. RG focuses on specific route information and NAV focuses on navigation in unknown networks, whereas DTI focuses on floating car information.

Sensitive goods monitoring (SGM): SGM provides information about sensitive goods such as perishable food products, drugs and the other goods classified as dangerous (about 0.32% of goods in Sweden [53]) to transport managers and government control units.

Staff monitoring (SM): SM collects information related to health, fatigue and so on about hauler company staff for staff administration (seen as the most expensive resource) and control, for example, by police, labour unions and so on. It is different from ODM and DP in that it focuses on companywide staff taking into account legal obligations.

Theft alarm and recovery (TAR): TAR provides real-time location and status information about stolen goods and vehicle to the goods owner, traffic and transport managers and so on.

Transport order handling (TOH): TOH provides real-time order information sharing between the goods owner, transport manager, driver and so on as well as the feedback when the orders are satisfied.

Transport resource optimisation (TRO): TRO attempts to optimise overall resources including road infrastructure, vehicle capacities, vehicle trips and so on so that the optimisation of subsystems (e.g. routing, driver planning) may not negatively affect other systems (e.g. road maintenance).

Vehicle follow-up (VF): VF collects and analyses vehicle performance-related data, for example, empty mileage, fuel consumption, vehicle statutes and so on, then reports such data to different interested groups, for example, fleet owners, vehicle inspection agencies and so on.

Table 1 Assessment of percentage (%) savings and societal values (M€) of TTSs for HGV transport in Sweden

PSIs	Fuel costs	Distance-based costs	Time-based costs	Transport administration	Accidents	Infrastructure maintenance costs	Noise and related external costs	Costs of building new infrastructure	Costs of missing and delayed goods	TTS value assessment, M€
PSI	832	515	725	311	201	67	306	408	244	
Values in M€										
ADL				0.1	0.5					1.32
AWI	0.1		5.0		0.1					37.53
DP			0.1	0.3						1.66
DTI	0.2		6.0						0.1	46.06
EC			0.1		15.0					31.15
EDI	0.1	1.5	3.0	0.1						30.86
ETA				2.0						6.21
ETM	0.1						0.4			2.06
FM				0.5						1.80
GEO				0.3						1.42
GI				0.4						1.49
IRM						1.0			0.4	8.30
ISA	0.1				15.0					31.26
ITP			0.1							3.16
NAV	1.0	3.0	2.0							38.27
ODM					1.0					2.01
OSM			0.1	0.1	1.0					3.05
PYD	1.0	0.1			0.1					9.04
RED	0.1		0.1	0.1						2.11
RG	0.1		0.1				0.1			2.11
RHW	0.1		5.0		0.3					37.69
RM			1.0	0.1	0.1					8.01
RTT			0.1	0.1						5.91
RUC	1.0	0.1	1.0			0.1			0.1	16.56
SGM				5.0	0.2					16.18
SM					0.5					1.01
TAR			0.1	0.1						37.56
TOH			3.0	0.1						22.06
TRO	2.0	3.0	3.0				0.1			54.39
VF	0.3	0.1	0.1							3.74
WI			0.1			5.0				4.06
XXL				0.1		0.1				0.38

Empty cell implies that we anticipate relatively insignificant savings

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Weight indication (WI): WI shares real-time information about the vehicle's total weight and the infrastructure conditions, road conditions and potential height restrictions with the driver and infrastructure owners. Theoretical and statistical analysis of weigh-in-motion at stations for HGVs in the UK shows a 36% potential time savings at gates, improved accuracy of weight information and shorter delay [22].

6 Results of TTS valuation

The proposed model (Section 3) is implemented in an Excel spreadsheet and the value of each application assessed under the following conditions: (a) the values were calculated considering the costs of HGV transport in Sweden, (b) the focus was on the societal effects of HGV transport only (societal effects from other road users, such as private cars, motorcycles etc, were disregarded), (c) the time period for which services were considered to start generating the calculated values was one year for all services, (d) TTS values were based on suggested percentage reductions of PSIs (in Section 3) according to the authors' perceptions of TTSs in Section 4, (e) the dependencies between TTSs were assumed to be pairwise as in (3).

Based on these assumptions the results shown in Table 1 were obtained.

Most of the studies seen above show that for PSIs that cover a large scope, percentage reductions are usually small (in the order of 0.1%), whereas trials that cover very narrow scopes typically report high percentage impacts. Since our PSI calculations were based on aggregated values, it was necessary to consider correspondingly small percentage assessments as in Table 1. For small percentage estimates, $0 \leq \alpha_{ik} \leq 0.15$ $i \in S$, $k \in P$, (5) can be approximated to (4) (see Section 3) in estimating dependencies between TTSs. For example, suppose that transport administration costs about 311 M€ per year in Sweden and can be reduced by EDI, GEO and GI with 0.1, 0.3 and 0.5% respectively and the interest rate is 4%. From (4), the estimated total benefits = 1.704 5 M€ and from (5), the estimated total benefits = 1.749 4 M€, can be approximated within an error margin of less than 2.5%. Therefore if the α-values are relatively small, we can ignore higher order terms in (5) and hence approximate (5) with (4). The result of TTS societal valuation without dependencies is shown in Fig. 2

Where relevant in our assessment, we referred to similar experimental results obtained in assessing potential savings of similar applications (see also the descriptions of TTSs above). The assessed values of the TTSs are obtained supposing each service is deployed independently of other TTSs. If the effects of other TTSs are taken into

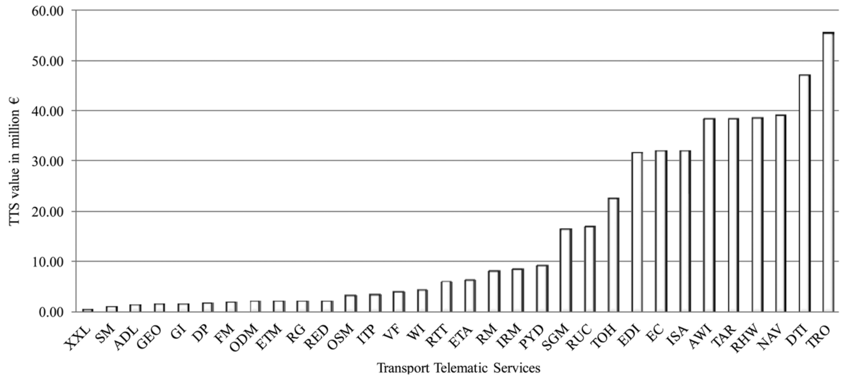

Fig. 2 *Chart showing the assessed TTS societal values for HGV transport in Sweden*

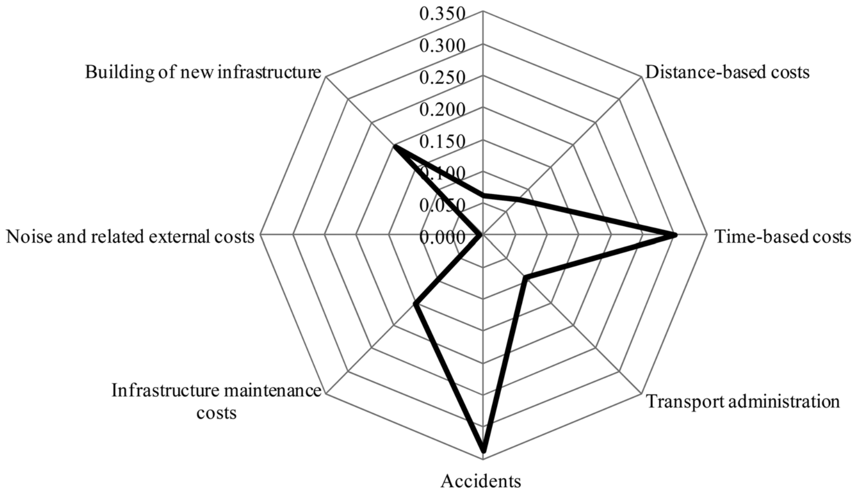

Fig. 3 *Extent of PSI reduction from the cumulative contribution of different TTSs*

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consideration, the above values will further decrease depending on the TTSs considered and the targeted PSIs. For example, suppose EC and ISA are implemented, each with the potential to reduce HGV-related accident cost by 15%. The resulting potential reduction will be $15\% + (100-15\%) \times 15\% = 0.15 + (1-0.15) \times 0.15 = 0.277\,5$ or 27.75% and not $30\% = (15 + 15)\%$. Thus, the dependency of 2.25% has to be reduced from the original value of both EC and ISA combined. Although the proposed approach works well for pairwise dependencies, we observed that it was complex for handling combinations with more than two services. The cumulative contribution of the above TTSs in reducing the societal costs for each of the PSIs shows that there is much room for new applications targeted towards noise and external cost whereas accidents and time-based costs are most likely to experience significant impacts under the current situation (see Fig. 3).

7 Conclusion and discussion

The purpose of this study was to use the criteria established in a previous study [5] and characterise TTSs in such a way as to enable quantitative analysis that will support decision making in selecting TTSs for investment. In order to achieve this purpose, a method for assessing societal value of TTSs was proposed. The method uses identified PSIs and calculates their societal costs. Potential percentage savings of different services for various PSIs were suggested and used to assess the value of different TTSs. We suggest that the values of PSIs and potential percentage savings are reestimated (e.g. based on new statistics and field trials) when the proposed model is to be applied. Pairwise dependency calculations were introduced to account for redundancies that may be involved when two TTSs address a common PSI. It was shown that the pairwise dependencies could be approximated to dependencies involving more than two TTSs. The results based on estimated values of PSIs and potential percentage savings show that important TTSs with significantly high societal impacts are transport resource optimisation, DTI, NAV,, TAR, AWI, ISA, EC, EDI, TOH, RUC and SGM. Efficient time management and reduced (impacts of) accidents are likely to benefit the most from TTSs as addressed in this study (Fig. 3). The method is simple, straightforward and useful for organisations such as governments and telematic service providers. The suggested PSI values and utilised percentage effects for different services still need further validation as more experimental work becomes available and anticipated TTSs are developed. In the future, PSIs can be more specific than they are today, addressing different areas.

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