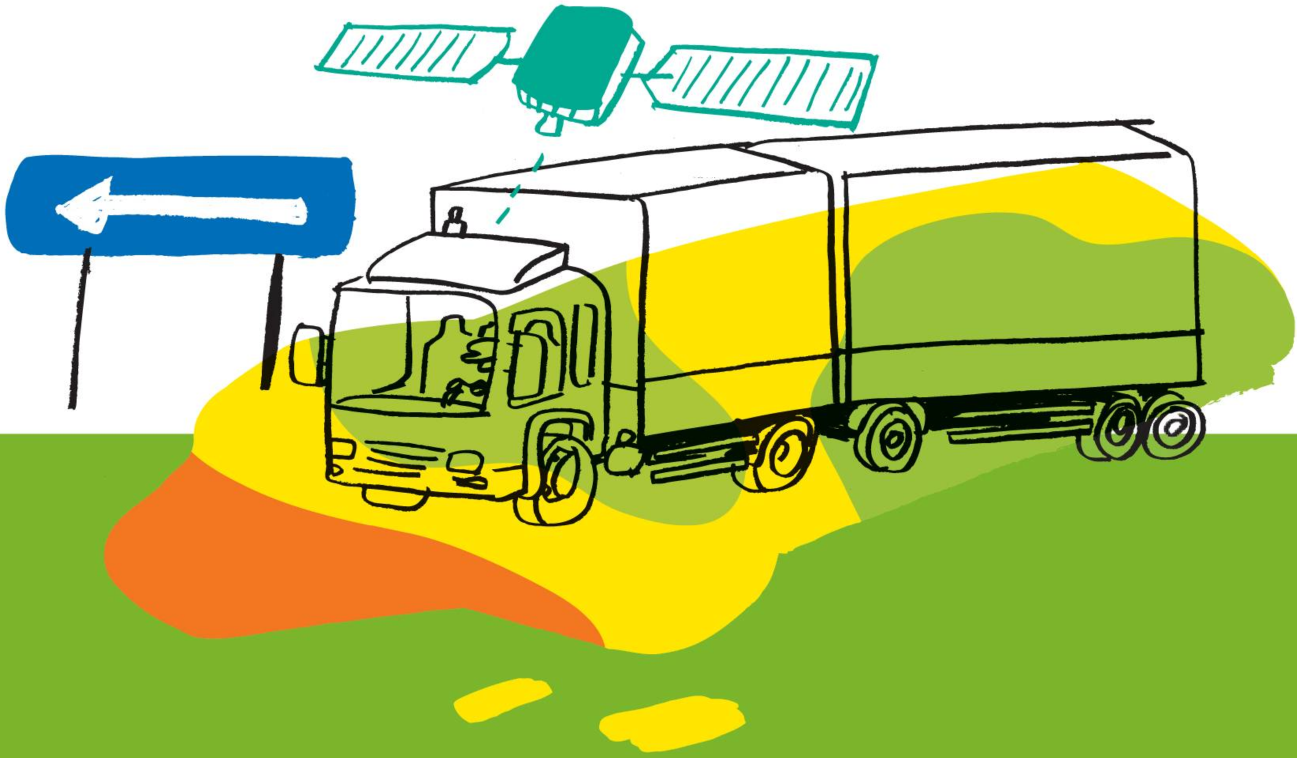

A Criteria-Based Approach to Evaluating Road User Charging Systems

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arena

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The ARENA project

ARENA is a national project that aims to build competence for a future introduction of a road user charging system for Heavy Goods Vehicles (HGVs) in Sweden. The project has been developed in accordance with EU Directives and the Swedish public authority plans to introduce a kilometre tax for HGVs. ARENA started in 2006 and is financed by the Swedish Road Administration and the Swedish Governmental Agency for Innovation Systems. NetPort.Karlshamn is the project coordinator.

The approach of ARENA is to take a wide view and not only focus on technology. Innovation potential, consequences and possibilities related to an implementation of road user charging is also important as well as respecting that different stakeholders have different needs and requirements. This requires interaction between relevant stakeholders at an early stage. The role of the ARENA project includes the following elements:

- acting as broker both between groups of stakeholders who normally do not meet and between competitors within the same group
- develop and support knowledge both within the project but also as a coordinator between other projects

A concept for a kilometre tax system in Sweden is developed with a functional approach, which does not prescribe any technical solutions. The concept is generic rather than specific, in the sense that it should be possible to implement the result in several ways. Hence, we are trying to define the system independently from its final technical design. The motivation for this is that the time horizon for realisation is far ahead, maybe 3-6 years, and we can expect considerably changes in technical preconditions over this period. The concept includes a number of characteristics that differs from existing systems, which will reduce cost, promote innovative solutions and enable European interoperability.

The work of ARENA will continue in ARENA 2.0, where the concept will be further developed in close cooperation with the industry and relevant authorities and administrations. A full-scale demonstration will be developed for the ITS World Congress in Stockholm 2009.

Swedish Road Administration

The Swedish Road Administration (SRA) is the national authority assigned the overall responsibility for the entire road transport system in Sweden. SRAs task is to co-operate with others to develop an efficient road transport network in the direction stipulated by the Swedish Government and Parliament. SRA has been commissioned to create a safe, environmentally sound and gender-equal road transport system that contributed to regional development and offers individuals and the business community easy accessibility and high transport quality.

VINNOVA

VINNOVA (Swedish Governmental Agency for Innovation Systems) is a State authority that aims to promote growth and prosperity throughout Sweden. VINNOVAs particular area of responsibility comprises innovations linked to research and development. The tasks are to fund the needs-driven research required by a competitive business and industrial sector, and to strengthen the networks that are such a necessary part of this work.

Abstract

A set of important criteria to consider when evaluating potential road user charging (RUC) systems are identified. These thirty-one criteria are grouped into five categories, charging accuracy, system costs and societal benefits, flexibility and modifiability, operational aspects, and security and privacy. The criteria are then used in a comparative analysis of five RUC candidate systems for heavy goods vehicles in Sweden. Two solutions are position-based systems and one is based on the use of tachographs. The two remaining solutions are very simple and based on fuel taxes. For each of the solutions we estimate how well it fulfils each of the criteria. One way of making general comparisons of the approaches is to give each of the criteria a specific weight corresponding to how important it is. We show that these weights heavily influence the outcome of the comparison. We conclude by pointing out a number of important issues needing additional attention in the process of developing a Swedish RUC system.

1 Introduction

The European systems for charging Heavy Goods Vehicles (HGV) are currently undergoing a change. The main reason is to make the road users compensate for the external costs that are caused by their transportations, i.e., internalisation of external costs. Until now, most systems for charging heavy goods vehicles have been based on a yearly flat fee, whereas the current developments are towards systems that charge the users for the distance driven with the potential to discriminate between road type, time of usage, environmental performance of vehicles, etc.

A Swedish Road User Charging (RUC) system, as proposed by the Swedish Government, is to be distance-based and cover both domestic and foreign heavy goods vehicles above 3.5 tonnes. The kilometre tax should cover all public roads, and in order reflect the marginal costs principle, it should be possible to differentiate between different types of vehicles (e.g., environmental performance classes), time of the road usage, and between different roads. This makes a Swedish RUC system more complex than the RUC systems in operation at the moment, e.g. in Germany only motorways are considered. Moreover, the Swedish system should be harmonized with other European systems existing and under introduction. This implies that system should adhere to the EFC-directive 2004/52/CE with the purpose of achieving a European Electronic Toll Service for heavy goods which is interoperable.

The purpose of this paper is to identify important aspects or criteria to consider when evaluating different solutions to the RUC problem and to illustrate how these can be used to make a structured assessment. It extends and updates the analysis made by Persson et al. (4) by considering additional criteria and an additional solution, discussing the criteria in connection to the motives for introducing a RUC system, and making deeper analyses, e.g., with respect to dependencies between criteria.

Most RUC systems are complex systems involving many actors, a lot of functionalities, hold sensitive information etc., which makes it important to consider additional criteria than just the cost of meeting the system requirements To meet such criteria is important in order to achieve acceptance among the involved actors. We also analyse some alternative solutions which cannot meet all the requirements, but meet some of them. In the next section we identify a number of motives for introducing a RUC system and identify some important criteria for evaluating such systems and their parts.

2 Evaluation Criteria

An important purpose of Swedish transport politics, and thereby of a Swedish RUC system, is to internalize external costs (6). Potential external costs to be internalized connected to heavy good vehicles are costs of: *road wear* (possibly including investments in infrastructure), *noise*, *accidents*, *emissions* (both locally and globally effecting) and *congestions* (7). An important aspect of external effects (and associated external costs) are environmental aspects. For practical reasons, however, it is not possible to internalize all external costs exactly. They simply depend on too many parameters.

We have chosen to let the extent to which these goals be represented by *charging accuracy*, i.e., how good is the system at charging the road user the correct tax, which is composed of:

- *Distance accuracy* – How exactly can the distance a vehicle has moved be computed?
- *Vehicle differentiation* – How well can the system differentiate between different types of vehicles, such as, weight class, emission class, etc.?
- *Time differentiation* – How exactly can the time when a vehicle has used a road be recorded?
- *Road differentiation* – How good is the system at identifying which route a vehicle has used?
- *Fairness* – Are all road users (liable for the tax) equally treated, e.g., foreign and domestic users?
- *Target accuracy* – Are all of the, and only the, intended users targeted?

We realize there may be additional criteria that can influence the external costs and effects, such as, echo driving, faulty engine, and reckless driving. However, we have chosen to not consider since it is doubtful that they can be captured a RUC system.

An additional potential motive for introducing a RUC-system is to steer heavy goods vehicles away from the local road network to the designated main roads when possible (which may not be directly related to external costs). Another potential motive is the possibility to steer traffic dynamically, for instance to reduce congestion. However, there are different views on whether road pricing on heavy vehicles actually have a significant effect on congestion control or not (5). The most important of the criteria above for traffic management are time, vehicle, and road differentiation.

Another potential purpose of a Swedish RUC system is to generate a general *tax income* for the government (or possibly for regions or local communities) or public funding for particular purposes, such as, financing of new roads and terminals, i.e., *special financing*. (See for instance SOU 2006:33 for such ideas.) The ability to achieve tax income using a RUC system is connected to charging accuracy. If the tax should be proportional to the use of the general road network, distance accuracy is most important. However, if it also should consider local characteristics, e.g., driving in a certain geographical area or using particular infrastructure, road differentiation is also of relevance. A summary of the relations between criteria and motives are presented in Table 1.

Table 1. The relations between system motives and some criteria; "X" indicates a strong connection whereas "(X)" indicates a less strong connection.

Criteria	*System motives*							
	Road wear	Noise	Accidents	Emissions (local)	Emissions (global)	Traffic control	Tax-income	Special financing
Distance accuracy	X	(X)	X	X	X		X	
Vehicle diff.	X	X	X	X	X	(X)	(X)	(X)
Time diff.		(X)	X	(X)		X		(X)
Road diff.	(X)	X	X	(X)		X		X
Fairness							(X)	(X)
Target accuracy				(X)			(X)	(X)

Fairness and Target accuracy has no strong connection to these aspects, but we include them here since they are strongly connected to acceptance of the system.

There may be additional motives for introducing a RUC system related the development of the society, such as, fostering the development of new technology within the county and provide support for more efficient transports. To address these positive aspects we also consider the following criteria:

- *Support for additional services* – How easy is it to add new services (to the basic road user charging functionality)?
- *Support technological development* – To what extent does the system provide incentives for development of new (efficient) technologies?

Potentially, there are many solutions that meet some or all of the requirements of a RUC system. To choose between these potential solutions, there are a number of relevant criteria that can be used. We have identified a set of criteria which have been discussed with participating stakeholders in the Arena project (http://www.arena-ruc.com/). Some of the criteria presented below are similar to the ones described in the report by Expert Group 9 (1), which is supporting the European Commission on the work on Directive 2004/52/EC:

System costs and societal benefits – How large are the system costs and societal benefits?

- *System cost* – What are the costs for government, haulers, and other actors?
  - *Investment costs*
  - *Operational costs*
  - *Enforcement costs* (including both operational and investment costs)
- *New equipment* – How large is the need for introducing and installing new (non-standard) in-vehicle equipment?
- *Communication need* – How much communication is needed, e.g., between vehicles and central servers?
- *Time to deployment* – How long time does it take to develop and deploy the system?
- *Fostering competition* – To what extent does the system offer incentives for a multitude of system providers?

- *Support technological development* – To what extent does the system provide incentives for development of new (efficient) technologies?

Flexibility and modifiability – How are the possibilities to adapt the system to future requirements?

- *Ability to adapt* – To what extent could the system be adapted to changing requirements, e.g. refined differentiation?
- *Scalability* – How well does the system handle large increases in the number of users, the road network, etc.?
- *Support for additional services* – How easy is it to add new services (to the basic road user charging functionality)?
- *Integration with services* (interoperability) – How well does the system cooperate with other relevant systems such as toll services?
- *Technological lock-in*: communication – How well does the system avoid technological lock-in with respect to communication technology?
- *Technological lock-in*: positioning – How well does the system avoid technological lock-in with respect to positioning equipment?
- *Enforcement possibilities* – What are the possibilities to implement different type of control and enforcement schemes?
- *Update effort* – How much effort is needed when new road sections are introduced, the tariff is changed, equipment update is needed, etc.?

Operational aspects – What are the effects of the system during operations?

- *Availability* – How robust and reliable is the system (for instance, is their a single point of failure)?
- *Maintainability* – How easy is it to maintain the system?
- *User friendliness* – How easy is it for the end-user to use the system, e.g., in terms of the manual procedures necessary and the installation? How good is the system at providing information to the user regarding, e.g., the fee/tax to be paid and where to find support in case of problems?
- *System complexity* – How complex is the system, e.g., in terms of number of and complexity of the equipment needed?

Security and privacy – What risks exist with regard to security and privacy within the system?

- *Risk of sabotage* – How large is the risk of system sabotage, what motives exist, and how easy would it be to sabotage the system?
- *Fraud resistance* – How difficult is it for users to circumvent security measures to escape taxes, e.g., by manipulation of equipment?
- *Risk of information theft* – How easy is it to steal information from the system?
- *Integrity protection* – How well does the system protect reliable information?
- *Privacy protection* – How well does the system protect user sensitive information?

I addition to the above criteria, one may also consider legislative restrictions. However, we find it useful to not view this as a direct criteria but is an aspect of time to deployment. After all, laws and regulations can be changed.

By using the presented criteria it is possible to evaluate the strengths and weaknesses of different solutions. Below we present and evaluate four potential solutions.

3 Potential Solutions

In the proposed Swedish system, it is implied that a good approximation of external costs requires the possibility to differentiate between different types of vehicles (e.g., environmental performance classes), time of the road usage, and between different roads. However, there are proposals (2) for systems which are not able to fully differentiate between road usage and time of usage. One approach is to use the digital tachograph and another is to simply use a fuel tax. The fuel tax option is relevant for comparison, since it at least has the potential to capture the CO2 emission effects accurately. Below five proposals are described:

A. The *"thin client solution"* is a proposed solution for a Swedish road user charging system for Heavy Goods Vehicles (HGVs) (3). It is based on that vehicles report their positions to a central system (an EETS-provider), whenever the mandatory On-Board Unit (OBU) knows that the vehicle is in Sweden. It is similar to the solution 1 (which is not the one denoted "thin client" in their proposal) in the "Report of Expert Group 9" (1). The basis of the system is an OBU, able to record Global Navigation Satellite Systems (GNSS) positions and to transmit them to a central server (not necessarily in real time). Also, Dedicated Short Range Communications (DSRC) between OBU and roadside equipment should be possible. The solution builds upon delivery of signed track logs including position data from the OBU, towards the EETS provider, using Public Land Mobile Networks (PLMN). Communication between two parties will be carried out by securing identity of the parties and that the messages are secured against message modification and fabrication; a secured kernel is used for this purpose. This solution allows for a rather open system structure in terms of different solutions for retrieving position data and sending these to the central server, either as a stream or in bulk transfer. Control functionality is carried out by real time communication using DSRC and by control of reported position data in comparison with other sources of information, e.g., tachographs or company tax declarations. Border crossing is dealt with by DSRC registration and stored information in the OBU of country borders in GPS format.

B. The *thick client solution*, is similar to the thin client, but with the addition of that maps and tariffs are included in the OBU, which needs to be possible to update. Further it includes a tax calculation capability, and hence, the tax calculations are communicated (not the positions per se). It is similar to the solution 3a in the "Report of Expert Group 9" (1). This solution is based on an OBU that is secured from manipulation and an important part of the control functionality is to make sure that no manipulation has occurred. Hence, it is based on a closed structure of the system, where the used OBU need to be certified and tamper proof. Border crossing is dealt with by using the maps in the OBU and possibly DSRC communication at the border.

C. The *digital tachograph,* see Kågeson (2) for a proposal. The core of the system is to use electronic devices (the digital tachograph) for recording vehicle movements. Originally, these were mainly motivated by the need to ensure that the time regulations for lorry drivers are obeyed. This type of electronic system is mandatory on new lorries in Europe (see http://www.eu-digitaltachograph.org/). The suggested control is carried out at regular vehicle safety checkups and possible road-side control. Border crossing can be dealt with by letting drivers making registrations of this, either electronically or as in case of the analogue tachograph by a picture taken by a camera. The exact dealing with foreign trucks and the enforcement in Sweden is not specified in the proposal (2). Also the method and frequency of reporting tax is unclear.

D. We make a distinction between two solutions based on fuel tax:

1. The *fuel tax system (D1)*, a special tax for fuel diesel usage in Sweden. Fuel sold in Sweden is simply taxed. The control is by controlling the fuel distribution in Sweden.
2. In order to avoid the situation of a significant part of road transports in Sweden is performed using fuel bought abroad, a declaration is carried out for trucks entering and leaving Sweden. For this solution, *fuel tax system (D2)*, we assume that there can be rather efficient ways of controlling this declaration, e.g., the use of electronic devices which can measure the amount of fuel in a truck. The system based on fuel tax may need to consider alternative possible usage of the fuel, i.e., consider potential exemptions for fuel usage for other purposes than HGV. That is, allowing the tax refund when showing the fuel has been used in another way.

4 Evaluation

We will now analyse the five candidate solutions using the different criteria presented above.

4.1 Charging Accuracy

With respect to *distance accuracy*, the solutions A, B and C, all have good potential for computing correct distances. However, for A and B, the accuracy depends on the frequency of position recording and the corresponding map matching, whereas C is sensitive to systematic errors in the tachograph. Solutions D1 and D2 are both dependent on the fuel consumption per kilometre which differs between vehicles and is difficult to estimate accurately. The ability to *vehicle differentiation* is rather good in solutions A to C, but there is a need to include methods for identification of vehicle configuration, i.e., whether a trailer is connected to the truck or not. Solutions A and B have greater flexibility in handling additional vehicle aspects than solution C. Solutions of type D cannot handle this differentiation unless it is closely related to fuel consumption, but it may in fact estimate the environmental external effects (CO2 emissions) of an additional trailer rather well through increased fuel consumption. Solutions A to C should be able to handle *time differentiation* rather well. However, C cannot perform time differentiation in combination with road differentiation. *Road differentiation* can only be handled by solutions A and B. *Fairness* between foreign and domestic vehicle transports can only be fully achieved in A and B (assuming EETS-providers exists for both foreign and domestic users), whereas fairness cannot fully be expected for C and D2 due to the expected extra work at border crossing for in particular foreign HGVs. As a fuel tax will probably affect others than the intended target group who are using diesel for other purposes, e.g., light trucks, cars and other types of machinery, the *target accuracy* is the lowest for solution type D and high for the other solutions. Solution D1 cannot handle vehicles which have filled the truck with fuel abroad.

4.2 System Costs and Societal Benefits

The *system cost* is anticipated to be the highest for A and B, since these solutions require development of central computing facilities and heavy use of the communication infrastructure, as well as the introduction of new equipment in vehicles either on a permanent basis or when entering the country. We anticipate their operational and enforcement cost to be high due to their advanced structures, whereas solution C has the potential to use equipment already in existence and included in the vehicle. The operational costs for C can still be of significance since it is likely that a new system for reporting tax is needed and the frequency for regular vehicle checkups may need to be increased. (The checkups are suggested as an occasion for tax reporting by Kågeson (2)) We believe that solution type D has the lowest costs since no new equipment is needed in the vehicles and no new ICT infrastructure needs to be developed and deployed. Solution D2 is more expensive than D1, in particular with respect to enforcement cost.

We anticipate a higher need of *new equipment* in cases A and B, where the need is the highest for solution B, where existing in-vehicle equipment cannot be used to the same extent as in A. The *communication need* is rather high for A, since the amount of position data that needs to be communicated to a central server is significant. Solution A communicates the majority of information in upstream direction, which in general offers less capacity as compared to the downstream. A significant part of the traffic in case B is assumed to be related to communication in downstream direction of, e.g., software and tariffs. The downstream communication for vehicles entering Sweden may be significant, if all map and tariff information is needed at entry. Solution B has the potential to aggregate the position information into tax calculations in the upstream communication. The communication need between a vehicle and a central server is marginal for D2 (only declarations of fuel at borders) and non-existing in solution D1. Limited information needs to be reported from the digital tachograph for tax computations in C.

We estimate the *time to deployment* to be shorter for D1 (no equipment in vehicles needed) and C (equipment in existence), but not for D2 due to development of fuel declaration system and not to be ignored, the process of ensuring adherence to the law (potentially by changing the law). For solution A, interfaces need to be developed, and for B, more complex equipment needs to be developed. The highest degree of *fostering of competition* is achieved in A (due to an open structure) and C (well defined units which can be produced by a number of providers), whereas B has the characteristics of a complex and closed system raising the bar for those planning to enter the market. We regard solution D1 as negative in this respect since there are no system providers between whom competition can occur. Solution D2 does not allow for much competition since it will probably be a very specialized solution used at border crossings. We believe that A is *supporting technological development* the most due to its flexibility in technology choices, while neither C nor solutions of type D support any significant development of new technology.

4.3 Flexibility and modifiability

The *ability to adapt* is the highest in A, since it has a more open structure allowing the use of different technologies. Solutions C and solution type D are hampered by the inability to adapt to new requirements, e.g. road tolls. Solution A has limits with respect to *scalability*, due to the need of communication and the fact that computations are done centrally, potentially in a single-point-of-failure structure. B imposes slightly less computational needs on central level. Solutions of type D have no problem with respect to this whereas some limits exist for C due to the central processing of information from tachographs. Solution A has good *support for additional services* due to its open architecture and positioning capability. B is also good due to the inclusion of both positioning capability and maps. Solutions C and solutions of type D have strong limits on additional services, which often requires position information. (See the project GIROADS (http://www.intelligentroads.org/) for examples of such services.) *Integration with services*, for instance road tolls, is naturally only possible with A and B, but not easily with C and D. In comparison, solution B has the greatest risk of causing *technological lock-in due to communication* due to is closed structure, whereas solution A is more tolerable to other means of communications. There is hardly any communication needed in C and D (however some need in case of D2), and hence, the risk of lock-ins is rather small. The situation is similar with *technology lock-in with respect to positioning*, except that no substantial difference between A and B can be foreseen. Solution A has requirements on non-tampered messages and secured identity and B the requirement of a certified OBU. We believe the *enforcement possibilities* and control possibilities are equally large for A (due to a rich availability of position data at central server to control) and B (due to more reliable method to read the state of the OBU). The situation is worse for C due to less rich information to control and unavailability of efficient status checks, e.g., by DSRC. For D, the information availability is even less. The *update efforts* are significant for B (downloading maps and tariffs and possibly software), but less for A. For C, changing to new tachographs causes update efforts, while for D1, no effort is required, but some for D2.

4.4 Operational aspects

The *availability* of the system for the user is the highest for solutions of types D (at least for D1) and almost as high for C (due to rather simple equipment). For A and B the availability is lower due to a more complex technology, and A may also suffer from its single-point-of-failure structure. C and in particular D are the solutions that have the highest *maintainability* relative score due to their simplicity. B has a reduced maintainability due to its more complex OBU. Due to its simplicity, at least D1 has the highest *user friendliness*, followed by D2 (due to extra work at border crossings may occur) and C. Due to the complexity, including difficulty to install, the user friendliness in A and B is lower. Solution B is probably better than A in this respect due to a potential ability to inform user of current taxes. As indicated, A and B have the highest *system complexity*, and D represents the least complex solution.

4.5 Security and privacy

The *risk of sabotage*, including the magnitude of potential consequences, is the highest for A and B due to their high complexity. The magnitude is even higher for B due to that all OBUs are exactly alike: Once a method is found to compromise one OBU, other OBUs can also be compromised. The risk is lower for C and in particular for solutions of type D due to their simpler structure. The *Fraud resistance* is comparably high for the simplest solution (D1) and less for the others. The *risk of information theft* is of course highest for A and B since more sensitive data (e.g. positions) is included in complex systems and less in C and D, where the least sensitive data exists in D. Likewise *integrity protection* is the highest for D1 and lowest for A and B due to the different occurrences of essential information (i.e. information crucial for the system). From the individual perspective, the level of *privacy protection* is similar but somewhat worse for A since position data, which is sensitive from an individual perspective, is sent to a central server.

4.6 Quantified assessment

We have quantified the assessment using a five-grade scale. The scale is relative in the sense that the grade for a certain criterion for a particular solution depends only how the other solution performs with respect to this criterion. Table 2 provides a summary of the quantitative evaluation of the five solutions.

Table 2. Summary of assessment using the relative scale "--","-", "0", "+", "++", where "--" indicates a very low merit of the proposed solution and "++" indicate a very high merit.

Criteria type	Criteria	A	B	C	D1	D2
Charging accuracy	Distance accuracy	++	++	+	-	-
	Vehicle differentiation	+	+	0	-	-
	Time differentiation	++	++	++	--	--
	Road differentiation	++	++	--	--	--
	Fairness	++	++	+	--	+
	Target accuracy	++	++	++	--	-
System costs and societal benefits	Investment costs	--	--	+	++	+
	Operational costs	--	--	0	++	+
	Enforcement costs	-	-	+	++	0
	New equipment	-	--	+	++	+
	Communication need	--	--	+	++	++
	Time to deployment	-	-	+	++	0
	Fostering competition	+	0	+	--	-

	Support tech. development	++	+	0	--	-
Flexibility and modifiability	Ability to adapt	+	0	-	--	-
	Scalability	-	0	+	++	++
	Support for additional services	+	+	-	--	--
	Integration with services	+	+	--	--	--
	Tech. lock-in: communication	-	--	++	++	++
	Tech. lock-in: positioning	-	-	++	++	++
	Enforcement possibilities	+	+	0	-	-
	Update effort	+	--	+	++	+
Operational aspects	Availability	-	0	+	++	++
	Maintainability	0	-	+	++	++
	User friendliness	--	-	+	++	+
	System complexity	-	-	+	++	++
Security and privacy	Risk of sabotage	-	--	0	++	+
	Fraud resistance	0	0	0	++	+
	Risk of information theft	-	-	+	++	++
	Integrity protection	-	-	0	++	+
	Privacy protection	--	-	0	++	++

5 Discussion

It seems clear that the simplest candidate system, the fuel tax system (solution D), has obvious advantages in some areas like system cost, operational aspects, and security and privacy. On the other hand, it has some serious problems as well, like low charging accuracy and flexibility. Almost the same applies for the tachograph (solution C) but with some (rather small) security and privacy problems. Solution A and B have their main merits in the ability to achieve a good charging accuracy and drawbacks in the form of comparably high system cost as well as potential scalability problems and security and privacy problems.

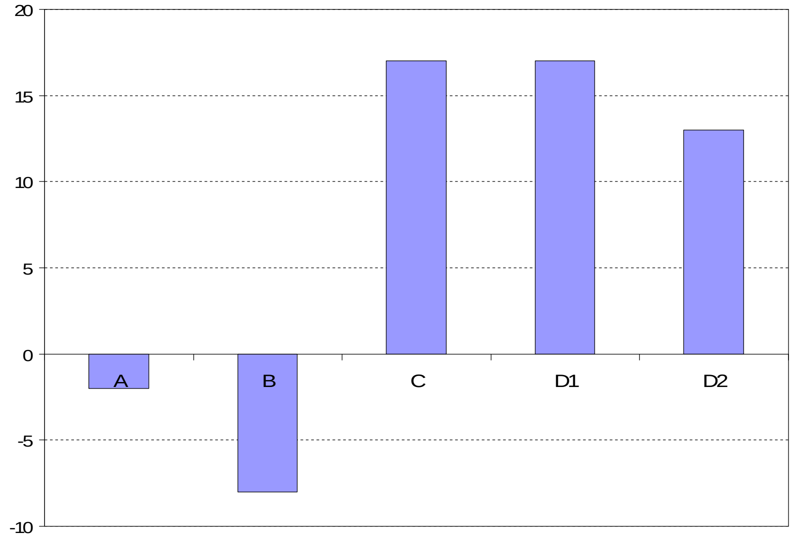
The result of our evaluation is somewhat different from the results of the evaluation done by Expert Group 9 (1), when comparing the Thin (A) with the Thick client (B). They anticipated the *communication need* (volume-efficient communication) of the thick client (B) to be much less than in the thin client (A). We argue that there is a difference, but probably rather small, since the update effort is higher in the thick client, which also requires communication. We have an equal potential of *integration with services* using solution A and B, whereas the Expert Group 9 argued that the solution B was better. Solution A supports integration better due to its more open structure. However, B is more suitable due to its potential of being easily integrated with other toll systems, e.g., the German Toll Collect system. We believe the enforcement possibilities are as high for A as for B; the results of the Expert Group 9, indicate a higher enforcement flexibility for B. We believe that one merit of the thin client is that actual positions are reported, whereas the thick client has potentially better flexibility in including different schemes for checking the status of the equipment in different ways (e.g. by road-side inspection by DSRC or by communication on mobile networks). This interpretation also affects the *fraud resistance*, which by the Expert Group 9 is claimed to be better through solution B than by solution A, whereas our suggestion is that they are roughly equally resistant (but on different merits).

Let us now focus on the criteria directly connected to the motives for introducing the RUC system, i.e., distance accuracy, vehicle differentiation, time differentiation, road differentiation, fairness, target accuracy, support tech. development and support for additional services. By applying the value of 2 for ´++´, 1 for ´+´, 0 for ´0´, -1 for ´-´, and -2 for ´--´, we can compute some summary quantitative relative measure for the different solutions. We can also do the for all criteria other than those connected to the system motives, and finally for all criteria. In Table 3 we see that solutions A and B meets the requirement (the motivational criteria) to a much higher degree than D1 and D2, and that solution C is between these. However, taking all criteria into account, we get the opposite result.

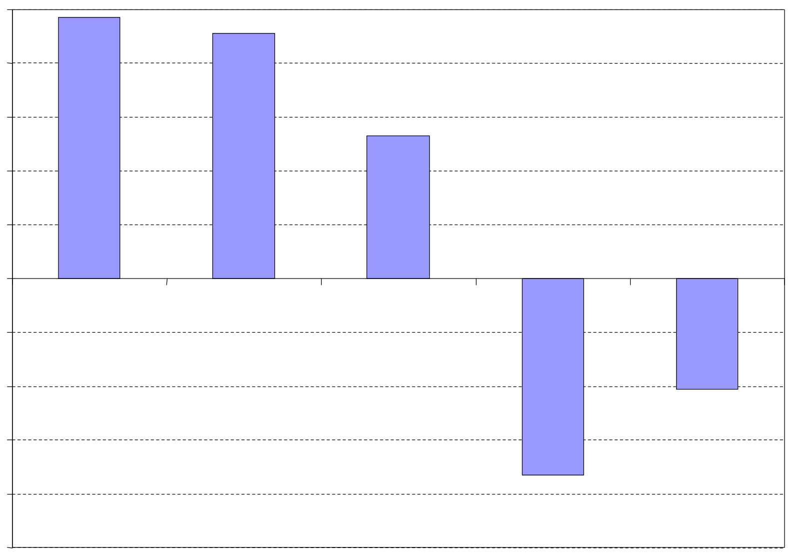
Table 3. Summary of evaluation scores.

	A	B	C	D1	D2
Motivational criteria	14	13	3	-14	-9
Other criteria	-16	-21	14	31	22
All criteria	-2	-8	17	17	13

There are a number of the criteria which are directly related to the acceptance of the system, which also is a factor to account for when choosing system and system design. In particular security and privacy aspects and user friendliness should be considered from an acceptance perspective. With respect to acceptance it is useful to look at the criteria from different stakeholders' perspective. One can at least consider four types of stakeholders: public authorities (including politicians), system providers, organisational users (e.g. trucking companies), and individuals (e.g. lorry drivers). This distinction has not been made in the analysis so far, (although the criteria meeting the motives of the system are certainly important for public authorities) but is probably of more interest if weights are applied to the different criteria. First for reference purpose one can illustrate the received scores in Table 3 in a graph.



If all accuracy criteria are given a weight of 10 and all others 1 the scores change accordingly



The criteria are not only partly hierarchical, e.g. maintainability affects system cost, but there are also some interdependencies, e.g. time differentiation is rather meaningless without ability to differentiate with respect to road. There are in particular high dependencies to be found for the criteria:

- Fairness with Distance accuracy, Vehicle differentiation, Time differentiation, Road differentiation and Target accuracy;

- Target accuracy with Vehicle differentiation, Time differentiation, Road differentiation, and Fairness;
- Risk of information theft with System complexity, Risk of sabotage, Fraud resistance, Integrity protection, Privacy protection.

6 Conclusions

Only the solution A and B (thick and thin client) meets the identified motives of introducing a Swedish RUC system. Our analysis shows, however, that a number of simpler solutions (tachograph and fuel tax based approach) may be more attractive when a number of system motives are ignored, or considered less important. Moreover, we have presented way of making general comparisons of the approaches by giving each of the criteria a specific weight corresponding to how important it is. We showed that these weights heavily influence the outcome of the comparison.

We see it as beneficial to proceed with some in-depth analyses. For instance, it is of most relevance to analyze system costs and societal benefits (primarily connected to road usage effects and tax incomes).

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