REALISTIC COST ESTIMATION OF AN INTELLIGENT TRANSPORTATION SYSTEM ROLL-OUT

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Abstract: This paper investigates the costs of rolling out an Intelligent Transportation System (ITS). Our cost model uses a set of possible technologies and applications, and can be further tailored to the most relevant scenarios. Unlike other research, this model investigates a joint roll-out, instead of separate applications. The reuse of existing infrastructure is also taken into account. This results in a more realistic cost estimation. Our model provides a cost break-up to identify the most crucial parts of the system in terms of costs. The case of the Belgian highways is used as a practical example.

1. INTRODUCTION

In essence, the concept of Intelligent Transportation Systems (ITS) implies the addition of information and communication technology to transport infrastructure and vehicles. A wide range of applications can run on this platform. For example, emergency services could automatically and immediately be informed when an accident happens (eCall application). Obstacle and Collision Warning can warn drivers for imminent collisions. More examples are discussed in the next chapter. In general, the intended benefits are increased traffic safety and efficiency and hence a positive impact on the environment through less traffic congestion.

The roll-out of such a system may require substantial investments in infrastructure. Moreover, many parties are involved, such as car manufacturers, network operators and traffic regulators. They need to be able and willing to cooperate and fairly allocate all costs and revenues. Here, we try and get detailed information on the required costs. There is little economic research on ITS costs so far, and it often focuses on a specific application (e.g. [1], [2]). A lot of this work is included on the Research and Innovative Technology Administration ITS overview site [3], but it provides building blocks rather than a complete picture. Some costs can be shared by many applications, which lowers the cost per application. Offering many services could also increase the users' willingness to pay (an important issue, according to [4]). Therefore, it is useful to consider a joint roll-out for a set of applications. To our knowledge, eIMPACT is the only (publically available) research project in which a similar investigation is made [5], though little information is given on what costs they have calculated and how. Thorough and complete cost information on the roll-out of an ITS appears scarce.

In this paper, we focus on cooperative applications, which require communication with infrastructure, unlike autonomous applications, which can be developed by manufacturers independently and are already on the market in different forms (e.g. ABS, ESP). We limit the roll-out to highways, thus omitting urban environments. This way, we group a set of applications that rely on a common infrastructure (the network) and we can investigate the impact of sharing general costs amongst all applications. To make our cost estimation more realistic, we will take re-use of existing network infrastructure into account. As a practical case, we've used the information of the Belgian highways and mobile networks.

In the next chapter, we define our roll-out scenario by selecting technologies and applications. Chapter 3 elaborates on our cost-model. In chapter 4, the results are discussed and we present our conclusions in the final chapter.

2. ROLL-OUT SCENARIOS

It is still unclear what the best roll-out scenario would be, and moreover, this is dependent on many factors, such as requirements of the end-users and the government, as well as technological and economical possibilities. Hence, the cost model is built to be flexible and allows many scenarios by configuring several building blocks.

2.1 Applications

The goal is to launch applications and they indicate our other requirements. However, there is no consensus on which applications should be rolled out and which shouldn't. This can partially be explained by the multitude of actors involved (e.g. driver preferences are different from technological feasibilities and government priorities). We've made a broad selection, based mostly on the work by [3], [6] and [7]. On top of safety applications, we've added recreational applications, because this could increase users' willingness to pay for the system. Our set of safety applications consists of eCall, Emergency Vehicle, Frontal Collision Avoidance, GPS Map Updates, Remote Diagnostics, Road Charging, Road Condition, Traffic Information and Traffic Management. The recreational application set contains internet browsing, audio and video streaming.

We describe applications by setting the most relevant parameters. The first is the percentage of drivers, who have a vehicle equipped with ITS technology, that will actually use the application. This is set to 100% for safety applications; for recreational applications, we estimate this will be 5% to 10%. The second is bandwidth use, and was estimated by analysing the size and frequency of messages. Finally, the complexity of the application translates to a development and maintenance cost (mainly personnel cost), as well as a server load.

In the model, we distinguish four options:

- only safety applications,
- only recreational applications,
- both,
- both, where the usage of recreational applications is set to 20%.

The last option is an extra test to check how future-proof the network is (as bandwidth demand continuously increases).

2.2 Network Technologies

In order to support our application set, vehicles will contain an On-Board Unit (OBU), which can communicate with Road-Side Units (RSU) or with the back-end/internet through an access point. The back-end is a control centre that runs and monitors applications centrally (Figure 1). This high-level architecture is in line with the European ITS Communication Architecture [8]. The network must meet the connection requirements of the applications. In this case, we distinguish three types of wireless access technologies:

- wireless medium to long-range unicast,
- wireless medium to long-range broadcast,
- wireless short-range unicast and geocast.

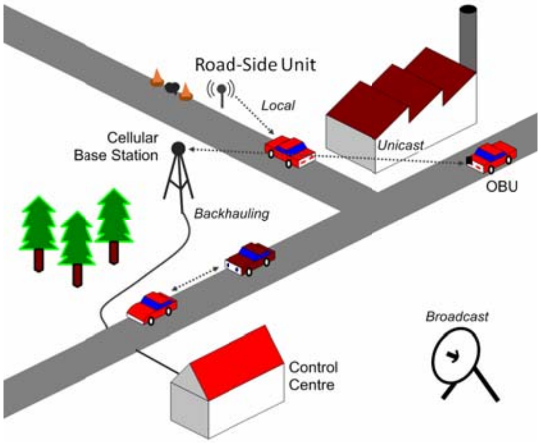

Figure 1: ITS components overview.

In case of long-range broadcast, contrary to unicast, bidirectional communication is not possible. It could be useful for preserving bandwidth in the network if all users require the same data (e.g. traffic information). Short-range communication can be cheaper than longer range, because it typically operates in unlicensed spectrum. But it is not always feasible (it would require too many RSU's). Fixed access, such as fiber, is only relevant as a backhauling solution, since OBU's obviously can't have a fixed connection.

For short-range communication, we only use CALM-M5 (this is the European version of IEEE 802.11p [9], also known as ITS-G5). CEN Dedicated Short Range Communication (DSRC) has a range of only 15m and does not support vehicle-to-vehicle communication (due to passive vehicle transporters). CALM-IR is based on directional infra-red communication and would thus require an expensive gantry over the road with one transceiver for each lane [8].

For broadcast we consider two options: MBMS or DVB-T. MBMS is a broad- and multicasting technique that can be used on top of UMTS and HSPA hardware. With Terrestrial Digital Video Broadcasting (DVB-T), traffic information could be sent to all vehicles using the DVB specifications for IP datacasting [10]. DAB was omitted, because it is far more limited in bandwidth, while the transceivers appear considerably more expensive. The use of a broadcast technology is optional (the medium-to-long range unicast network can also send messages to each vehicle).

Finally, for medium- to long-range unicast, we consider HSPA, mobile WiMAX and LTE. Older technologies would only support the most basic of applications, while HSPA is currently rolled out by almost all network operators that provide UMTS [11]. We assume HSPA will be the standard by the time an actual ITS roll-out takes place.

For the broadcast and local communication technologies, we used the standard specifications performance indicators, because it is unlikely that the ITS' requirements will exceed its capabilities. For the medium to long-range unicast technologies, we must take into account that the standard specifications are often not realizable in practice. The Erceg C path loss model shows that the realistic communication range for unicast technologies is a lot smaller than the standard indicators. For example, for mobile WiMAX, we take a range of 450m into account (inter-site distance 900m).

2.3 Other Building Blocks

Other relevant factors in determining the scenario are the adoption rate, the roll-out speed and the required availability of the services.

The adoption of the system is difficult to estimate, as there has never been an actual roll-out to compare with. Also, it is unclear whether the system should be enforced (e.g. obligatory integration in all new cars) or not. We've considered three possible adoption rates (Figure 2). Enforced adoption is based on the sales of new cars. The other options are modelled by a typical Compertz-curve; one version assuming a high acceptance, the other a low one.

We should also determine the speed of the roll-out. When an ITS is launched, it will not be used by everyone at all times right from the start. There can be a (long) transition period. There is an opportunity to save costs by postponing parts of the installation until the initial infrastructure is no longer sufficient. In Figure 2, a three-phased roll-out is assumed and indicated by the vertical bars. The initial installation is sufficient to cover an adoption rate of 30%, in case of enforced adoption. After three years, an additional installation is done to cover 60%. Finally, in year 8, the infrastructure is expanded to cover an adoption rate of 100%. Up to five phases can be defined in the model.

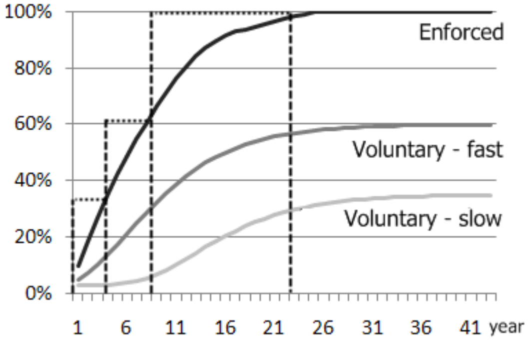

Figure 2: adoption scenarios, with indication of a three-phased roll-out for the enforced option.

The amount of bandwidth required in a base station will depend on the number of connected vehicles to it, and thus on the traffic situation. The worst case is one where there is a traffic jam in both directions. The odds of this happening, depends greatly on the exact location and it may not be necessary that the system can handle such extreme traffic circumstances everywhere. We distinguish five traffic circumstances with an increasing vehicle density and thus increasing communication requirements: (i) no traffic, (ii) sparse traffic, (iii) regular traffic, (iv) a one-way traffic jam and (v) a two-way traffic jam. The model allows defining the percentage of the highway that is equipped for each circumstance. This can be different for each phase, i.e. to allow an incremental increase.

3. COST MODEL

3.1 Capacity Demand

For any scenario, we need to know how much bandwidth and how many connections are required. Based on the application set and its parameters, we can calculate the average bandwidth consumed by one vehicle. In order to calculate the network load, we also need to know the vehicle density. We calculate the density for each of the five traffic situations. In case of no or sparse traffic, the network load is irrelevant, because the equipment is independent of the bandwidth usage (none in case of no traffic, just enough to have full coverage in case of sparse traffic). For regular traffic, we calculate the number of vehicles on one lane by making a few simplifying assumptions. We consider all vehicles to drive exactly the maximum speed, with two second intervals (based on the rule of thumb for safe driving). In this case a simple formula calculates the number of vehicles with average length *a* and with an average of *v* meters per second on one lane of a piece of highway with length *L*:

$$Number\ of\ vehicles = \frac{L}{a + 2.\mathrm{v}}$$

This is then multiplied by the number of lanes. In the model, this is slightly enhanced by also taking into account the percentage of trucks, their lower maximum speed and higher average length. While this model obviously simplifies reality, the calculated 150 vehicles/km on a 6-lane highway are in line with previous work that determined vehicle density by traffic measurements provided by the Flemish government [12].

In case of traffic congestion, a different model is used. Here we assume that vehicles move in waves: one vehicle fills the empty spot in front of itself, followed by the next vehicle. This way, only a percentage *p* of vehicles is moving. Non-moving vehicles have a small distance d_{still} between each other, while moving vehicles are driving when there is a larger distance d_{drive} in front of them. Again, a simple formula follows (which is again corrected for the percentage of trucks on the highway):

$$Number\ of\ vehicles = \frac{L}{a + d_{still} + p.d_{drive}}$$

This leads to an estimate of 631 vehicles/km on a 6-way highway in case of a two-way traffic jam. In case of a one-way traffic jam, we combine three lanes of regular traffic and three lanes of congested traffic, or 390 vehicles/km.

The network load on the highway is then simply the number of vehicles on that part, times the average bandwidth required.

3.2 Network Dimensioning

The network needs to be designed such that it can meet the capacity demand at the lowest cost. The input information is: (a) the capacity demand, (b) the distribution of existing sites and to what extent they can be reused, and (c) the technological parameters. Dividing the available bandwidth by the capacity demand gives us the required site density. However, the highway is not uniform and neither is the existing network site distribution. Information on traffic jams and base station locations is publicly available in Belgium. A visual check reveals that the densest regions of existing sites mostly overlap with the busiest parts of the highway. We assume that the overlap is complete, as this greatly simplifies the calculation. The total number of sites available next to the highway can be obtained by combining GIS-data of the highways and the network sites. There are about 650 sites located within 200m of the highway. Conceptually, the model calculates the number of new sites as follows. First, we split the highway into many small parts (the model works continuously, not discrete), and sort these from least to most busy. The busiest parts of the highway will also require equipment to handle the heaviest traffic situations. The capacity demand we calculated before can thus also be sorted from low to high and mapped on each part of the highway. Similarly, we also map the existing site distribution on it. Basically, we now have the number of required sites and the number of existing sites, for each part of the highway. Subtracting one from the other gives us the number of new base stations and the required equipment to connect them.

3.3 Cost Overview

In order to get a view on all costs, we consider the different phases in the life of the project and the different aspects of each (Figure 3).

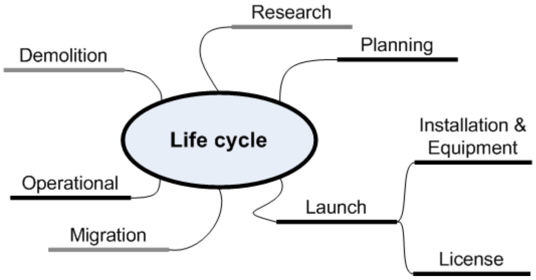

Figure 3: Overview of phases in ITS life cycle.

The planning and research phase can be a bit hard to differentiate from each other. Moreover, research costs by private companies will be integrated in the price of the final products and services they offer. Therefore, we only take into account the cost of planning the locations of new sites and transceivers. This is calculated by using the number of network planners as a cost driver.

The installation and material costs are part of the launch of the system, but they are spread in time due to the phased roll-out. The new network infrastructure leads to a bill of material, and installation and transportation costs can be estimated by using distance driven and hours spent as cost drivers. The existing network, such as base stations and backhauling connections, can be re-used, but we assume that only 40% of the transceivers will actually be available, because that network is also used to serve cell phone users. Lease costs are taken into account, estimated at about 10% of the acquisition cost per year.

The migration (or connection) cost is simply the installation of an OBU in this case. We assume the unit itself will cost about 200EUR (based on building blocks and also similar to Personal Navigation Devices). Aftermarket installation could prove difficult: a connection must be made to the internal CAN-bus and an antenna must be placed outside the vehicle body for good reception. There is little information available on this point; we assume a fixed fee of 100EUR for installation.

The operational phase contains many elements. First, there is the continuous cost of infrastructure, which includes the replacement of equipment (such as new transceivers), the lease costs of equipment (such as servers) and energy consumption. Second, Customer Relationship Management requires a helpdesk and marketing efforts. Third, the assets (equipment and software) must be maintained. Finally, the control centre needs to be up and running. Lease and maintenance costs are estimated as a fixed percentage of new costs (resp. 20% en 15%). The energy consumption is calculated by using the bill of material and equipment estimates. Marketing is considered to be a government campaign, which starts initially at 250.000 EUR, but decreases over time, proportionally to the number of non-users. For the helpdesk and the control centre, we estimate a number of employees based on the applications. Their wages are the main cost driver, but we take a general overhead of 30% into account.

A break-down phase doesn't seem relevant in this case.

4. RESULTS

Figure 4 shows the impact of the adoption scenario and the selected medium to long-range unicast technology. Both safety and recreational applications are rolled out. The other scenario building blocks were set to identical and logic values. Their impact is discussed further.

The cost figures shown are the Net Present Cost of the cash flows of the roll-out during the first 10 years. All further cost references are calculated in this fashion. A discount rate of 15% was used, because of the high risks associated with the project. As a reference, the Belgian highways are about 1.747km long.

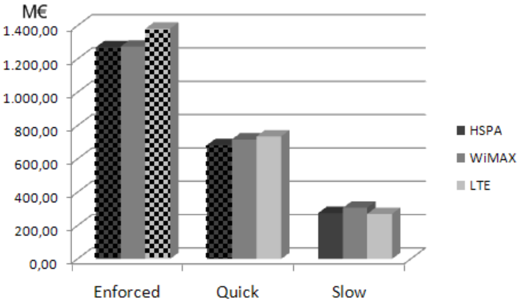

Figure 4: Cost for different adoption and technology scenarios, in case both safety and recreational applications are rolled out. Checked bars are invalid options.

Our model takes the maximum number of connections per base station and the connection duration versus connection set-up time into account. In some cases, it is technically not feasible to realize a roll-out scenario, because these constraints are broken. This is also indicated in the graph. This can be avoided by lowering some roll-out requirements (i.e. not equipping parts of the highway to handle two-way traffic jams).

In all these cases, no broadcast technology was used. The use of DVB-T causes a cost increase of about 47%. This can be explained by the cost in the OBU for the extra receiver, as well as data subscription costs for each user. MBMS in combination with HSPA realizes a cost reduction of only 1,5%, but was not used in the graph for a better comparison. The cost reduction is to be expected, because the hardware equipment is identical. However, using the broadcast functionality frees up some bandwidth of the unicast functionality, which translates in a few base stations less.

Let's investigate the impact of changing the application selection. Opting for only safety or recreational applications leads to a very similar cost, which is only about 10% to 20% smaller than combining both. Increasing the use of recreational applications to 20% is not a valid option, unless adoption occurs slowly and WiMAX is used.

We have also assumed a four-phased roll-out and a balanced mix of traffic situations. In comparison, a full roll-out from day one would cost about 68% more.

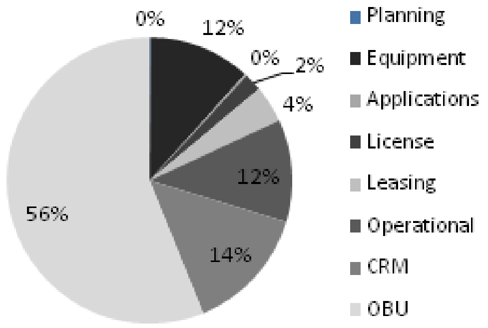

Figure 5: Break-up of total costs after 10 years for WiMAX scenario with voluntary, fast adoption.

The cost impact of re-using existing equipment is actually limited. When we compare a WiMAX roll-out with or without re-use of existing base stations and backhauling connection, the total cost is only 8% higher. We do note that a lease fee of 10% to 15% may be conservative.

In the rest of the discussion, we work with the scenario of mobile WiMAX and a fast, voluntary adoption. We will now investigate the cost break-up more in detail (Figure 5). The biggest cost by far is the OBU. This can easily be explained, considering it is a cost of a few hundred euros per user. The second most important cost is CRM, which we have calculated as a variable cost that increases in line with the total number of customers. Different implementations may avoid or lower this effect, e.g. by charging a tariff for calling the helpdesk.

A more practical way of looking at the result, is calculating the cost per user. The direct cost is the OBU, which was already discussed. If we take the sum of all non-OBU costs over the course of 10 years and divide this by the number of customer-years, we obtain a cost of about 48EUR per customer per year. Assuming an OBU also lasts for 10 years, the total cost is about 80EUR per customer per year. There is a big impact from the adoption rate. Enforced adoption only lowers this cost to about 65EUR, while a slow, voluntary adoption increases it to 250EUR.

5. SUMMARY & CONCLUSIONS

In this paper, we've presented a model that calculates the costs of rolling out an ITS on highways with a set of cooperative applications. Our approach is unique, because we've considered the joint roll-out of many applications, including recreational, and also took existing equipment into account.

The combination of applications over the same infrastructure has little impact on the total costs, as long as the bandwidth requirements remain moderate. This can be a great way to increase the value of the system, without increasing the costs. The re-use of equipment had a limited, but positive effect.

The results also indicate that especially HSPA is not a future proof technology for this type of applications and that broadcast technologies offer limited economical benefits. In its current form, LTE does not offer improved functionality over mobile WiMAX. The model indicates it is more expensive, but reliable cost estimations for LTE equipment are hard to come by and, as LTE is also much more recent, cost reductions can be expected in the upcoming years. It is also apparent that considerable savings can be made by fine-tuning the roll-out.

While it is not our intention to deliver a detailed planning and exact cost calculation tool, the absolute figures are nevertheless a good indication of the order of magnitude of the costs. The high figures can be relevant when considering the role of the government or private parties in the roll-out of an ITS.

The great impact of the OBU and CRM in the total cost makes these obvious candidates for future cost reduction investigations. Finally, we noticed that the adoption rate has a big impact on the cost, while it was very hard to gather reliable information on this input parameter. This suggests that this, too, should be the focus of further study.

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REFERENCES

[1] S. Kang, D. Gillen, 1999, *Assessing the Benefits and Costs of Intelligent Transportation Systems: Ramp Meters*, California PATH Research Report

[2] D. Levinson, D. Gillen, E. Chang, 1999, *Assessing the Benefits and Costs of Intelligent Transportation Systems: The Value of Advanced*

Traveler Information Systems, California PATH Research Report

[3] http://www.its.dot.gov/index.htm

[4] RACC Automobile Club, 2007, *Stakeholder utility, data privacy and usability analysis and recommendations for operational guarantees and system safeguards: Europe*, Public deliverable D.DEPN.4.1 of the FP7 CVIS project

[5] H. Baum, T. Geissler, U. Westerkamp, C. Vitale, 2008, *Cost-Benefit Analyses for stand-alone and co-operative Intel-ligent Vehicle Safety Systems*, Public Deliverable D6 of the FP6 eIMPACT project

[6] ETSI, 2009, *Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Definitions*, Standard No. TR 102 638

[7] Car 2 Car Communication Consortium, *C2C-CC Manifesto*, 2007

[8] M. Bechler, H. Berninger, T. Biehle, T.M. Bohnert, R. Bossom et al., *European ITS Communication Architecture*, deliverable of the COMeSafety project

[9] R.A. Uzcátegui, G. Acosta-Marum, *WAVE: A Tutorial*, IEEE Communications Magazine, pp. 126-133, May 2009

[10] W. Vandenberghe, P. Leroux, I. Moerman, F. De Turck, P. Demeester, *Design of a Scalable ITS architecture based on IP Datacast over DVB-H/SH*, 8th International Conference on ITS Telecommunications (ITST), Phuket, Thailand, 2008.

[11] Global UMTS and HSPA operator status, available http://www.3gamericas.org/documents/Global_3G_Status_Update.pdf, 9/2009, accessed 6/2010

[12] W. Vandenberghe, D. Carels, I. Moerman, P. Demeester, J. Bergs, E. Van de Velde et al., *Road Tolling* 2^E2 *impact study*, deliverible of the IBBT NextGenITS project, 2009