ROLLOUT MODELS FOR AN INTERNET SERVICE ON TRAINS

J. Van Ootegehem, B. Lanno, D. Pareit, D. Colle, I. Moerman, M. Pickavet, P. Demeester
Ghent University – IBBT, Dept. of Information Technology (INTEC),
G. Crommenta 8 bus 201, 9050 Gent, Belgium, jan.vanooteghem@intec.ugent.be,
tel: +32 9 33 14981, fax: +32 9 33 14899

ABSTRACT

Internet on the train has gained more and more interest the last few years. Most railway companies involved in such real-time communication projects are envisaging the attraction of potential new rail customers, improvement of their image or optimization of some cost processes. A business case, applied to the Belgian railway network, is elaborated for analyzing the profitability of an Internet service on trains. As the rollout (both sequence and speed) of a new communication network for trains is a very decisive parameter in the model, several heuristics are compared and evaluated to improve the feasibility of the case.

KEYWORDS
Internet on trains, Business model, Rollout schemes

INTRODUCTION

Internet on the train has gained a lot of interest in the railway sector over the last few years. Many railway operators are seeing this as an opportunity for long-distance (high-speed) train lines to compete with short-range airline services. Thanks to the availability of an Internet connection, train passengers travelling for several hours might spend their time more useful for work or entertainment purposes. Complementary to this long-distance train scenario, this paper focuses on a dense railway network, and on the advantages of offering an Internet service to commuting passengers. Every day millions of people are spending on average about 45 minutes on a train while travelling to and/or from work. This is a huge customer base, deprived of broadband access connectivity. Besides passenger services, the network connection could also be used by the train operator for interactive and high-priority services such as train monitoring, video surveillance (CCTV) and communication (e.g. VoIP) between train personnel. Depending on the services offered, the network requirements – e.g. high bandwidth, low latency and jitter, and a continue network connection – can strongly differ and the technology choice must be made in this way.

In section 2, we briefly discuss the technical solutions currently used for setting up and maintaining a network connection for Internet onboard the train. In section 3, we outline our generic Tr@ins business model. Section 4 shows our heuristic schemes for optimizing the rollout of the considered communication network. The paper ends with some conclusions.
TECHNICAL SOLUTIONS

Two different network parts can be distinguished when setting up a network connection from onboard the train. First, an outdoor network has to be set up and maintained between the moving train and the surrounding geographical area. Three main types of networks (mobile, wireless data and satellite) can be used. Secondly, the Internet users (i.e. passengers as well as personnel) are connected to the outdoor network via an indoor network in the carriages. The main technology used for this part of the network is WiFi. The focus of this paper however is limited to the outdoor network, and the mentioned networks are extensively compared to each other.

Mobile networks are made up of a number of radio cells, each served by a fixed base station (BS). This cellular approach is used to provide radio coverage over a wide area (e.g. nationwide coverage). The primary requirements of these networks, typically operated by telecom operators, are good coverage and high mobility, rather than high bandwidths. The main technologies in this category are GPRS (indicated as 2.5G), UMTS (3G) and its successor HSDPA (3.5G). Wireless data networks form an alternative to the mobile networks. To cover a certain rail section, new base stations have to be installed along the tracks, and hence, such a network is often referred to as a dedicated trackside network. Directional antennas can be used to cover a large track distance with high bandwidths. Technologies belonging to this category are WiFi, WiMAX and Flash-OFDM. Satellite networks are interesting for covering large train networks as most of them have a large footprint. In this way handovers - required for the above two terrestrial networks to reconnect from one base station to the next one - can be avoided. High data rates can be reached with one satellite for the duration of a trip. The major drawbacks are a strict line-of-sight (LoS) requirement and a high end-to-end delay.

Due to bandwidth limitations, coverage problems, LoS requirements, train speeds, cost issues, etc., a combination of the above technologies is often required for offering a seamless network connection and/or high quality of service. In this paper, we define 7 technical cases that cover most of the commonly used network combinations. Mobile networks are limited to a general HSDPA/UMTS network, assuming a maximum bandwidth of 900 kbps downlink, 384 kbps uplink (e.g. corresponding to one HSDPA channel or multiple UMTS channels in parallel), and as wireless data network we opt for WiMAX. Case 1 only uses the (currently available) HSDPA/UMTS networks. The main drawback is the limited bandwidth, which will probably be insufficient to cover e.g. a peak-hour train carrying 1000 passengers or more. Case 2 also starts with this HSDPA/UMTS network as first option but gradually switches to WiMAX where bandwidth limits are exceeded. In case 3, for some heavily used rail sections (e.g. between large cities), the transition to WiMAX is forecasted in advance and the sections are equipped with WiMAX from the beginning. Case 4 is a variant of case 3, in which WiMAX base stations are installed as hotspots in stations where trains, offering the Internet service, are passing. For case 3 and 4, the technology choice for the remaining parts of the railway network is based on the required bandwidth (cf. case 2). Case 5 is the opposite scenario of case 1 and deploys a full WiMAX network from the outset. The two remaining cases use a satellite network. Case 6 only uses a satellite connection for the downlink (i.e. one-way satellite) and the HSDPA/UMTS network is used for the uplink, as well as gap filler technology in areas without satellite reception. Case 7 makes use of a two-way satellite connection, thus for downlink as well as uplink, and mobile networks are again used as gap filler technology.
GENERIC TR@INS BUSINESS MODEL

A generic business model was created within the IBBT Tr@ins project to analyse different technical cases for offering broadband Internet service on trains. The model consists of a series of interconnected building blocks. The first block contains the forecasting model for predicting the number of train passengers, defining the rollout scheme and calculating the number of potential Internet users. The next step is assigning the appropriate technology to each rail section, based on technical limitations. In a finale step, a cost/benefit analysis is made for the different technical cases. The output of our model is the comparison of these cases, in terms of potential revenues, and investment and annual costs. A first version of the model was presented in [1].

Forecasting model

The passenger forecasting model predicts the number of passengers per train relation between each station. As this information could not be retrieved from public information sources, we created our own prediction model. The first step in the forecasting model is the aggregation of information from several sources. Railway network input contains all unique railway sections between all stations, combined with their length. Train relation input offers information about the stations, number of trains, etc. The distance as well as the duration of the route of each train relation is calculated. This input is required for the passenger prediction model.

Determining the number of passengers on a specific section is not that easy since passengers travel between several cities and pass several sections of the railway network. Therefore we created a simplified model for solving this problem (Formula 1). The passenger distribution (PD) is based on several parameters. For each section between two stations, we calculate an importance factor (I) based on three input parameters: the number of inhabitants in the region of the stations [2], the number of employees in the region of the station [2] and the distance of the section. For a specific section between two stations, we take into account the two previous and the two next stations, except at the beginning and end of a train relation. This delivers six stations, numbered from a to f, with the track c-d as considered section. The first part indicates the overall importance of the most influencing sections on the train relation e.g. between the largest cities, and receives a weight factor 5. The second part indicates several small sections with a maximum of 4 stations included and always containing section c-d. This gives in total six terms, each having a weight factor of 1.

\[
PD_{cd} = 5 \cdot I_m + (I_{ac} + I_{bc} + I_{cd} + I_{de} + I_{ef} + I_{fc})
\]  

(1)

Where:
- PD = passenger distribution over a specific section c-d
- I = importance factor
- a, b, c, d, e, f = stations on the considered train relation
- m = aggregation of the most influencing sections

After we calculate the distribution of passengers for a specific train relation, we allocate the number of travellers to each section. This is based on the number of seats available on each
specific relation. Train type, number of carriages, seat occupancy ratio, etc. are taken into account. For the seat occupancy parameter, we assume 35% for intercity trains (IC) and 25% for interregional trains (IR) over a day. Another important factor is the passenger distribution over a day [2], where we have taken into account that the number of seats is restricted in peak hours.

Starting from the passenger prediction model, we calculate the potential number of users for the Internet service. Based on the results from the market study performed within the Tr@ins project [3], a forecast is made of the potential market. The results are fitted on a Gompertz curve [4]. The adoption percentages after 10 years are 16.9% and 9.7% for first and second class passengers respectively. Another parameter is the modal switch between second and first class, which can result in an extra revenue flow for the train operator [5].

**Technology assignment**

Based on the number of Internet users, we determine the appropriate technology for offering the service. We assume that each user pays for a certain guaranteed bandwidth. Due to the fact that not all passengers use their connection at full bandwidth at the same time, a multiplexing factor is applied. In our case, we assume a dedicated bandwidth of 30 kbps downlink (7.5 kbps uplink) roughly equals a user experience of 1 Mbps downlink (256 kbps uplink). This experience is comparable to a fixed broadband Internet connection today available at home.

For each of the defined technical cases, we calculate the number of Internet users per technology, based on the assignment of the appropriate technology per railway section. This number of users is calculated by dividing the total passenger kilometers per technology by the average distance per trip per passenger [6]. We also deduce the number of kilometers track covered with wireless data networks, leading to the number of base stations required, and the bandwidth consumed by each technology (mobile data traffic per train, number of satellite links).

**Cost/benefit analysis**

The cost analysis is split up in capital (CapEx) and operational expenses (OpEx) for each technical case. CapEx is furthermore divided in train equipment and network equipment. For the first part, equipment is split up for master and slave carriages. The master carriage contains the outdoor antenna as well as the rack with network connection modems for monitoring and coordinating the onboard network. Slave carriages are only equipped with an onboard WiFi network. There is always one master carriage per train. In case multiple units are combined, all units separately connect to the outdoor network via their outdoor link. Satellite antennas are more expensive than UMTS or WiMAX antennas due to the needed moving parts (pointing and tracking components). Network related CapEx contains costs for rolling out a dedicated wireless data network, as well as costs for the network operation center (NOC), which monitors all trains and data traffic. The costs for the first category include acquiring ground for sites, poles, base stations, sector antennas, backhaul links and core equipment. We assume a certain amount (fixed at 75%) of the poles along the tracks, which are currently deployed for the dedicated GSM-R network, can be rented from the railway infrastructure owner [7]. The operational costs (OpEx) can be split between service and network related costs. The first category, including sales, billing, marketing and helpdesk, is required for offering the service and is independent of the proposed
technology. Maintenance and repair for train equipment and NOC are a percentage of the related CapEx costs. Network planning and operational costs depend on the technical scenarios and the combination of technologies. A critical OpEx cost is bandwidth consumption. Dedicated networks are directly connected to a fiber network along the tracks, which makes them relatively independent of the consumed bandwidth. Mobile data traffic is calculated per train (several mobile data SIM cards can be used in parallel) and is very expensive, certainly when subscription limits are exceeded. Satellite links are based on peak moment consumption, thus leading to an overcapacity and inefficient usage in non-peak moments.

Two revenue schemes are proposed in our model. The first consists of a full paying service for every user. In the second scheme, first class users get free Internet access. The purpose of the second scheme is to gain extra revenues from a higher modal switch from second to first class (an increase from 1% to 3%). Internet service users on the train might upgrade for two reasons. First class seats offer a quieter and more spacious environment to work. A second reason might be a free Internet service for first class passengers as opposed to second class passengers. In our results, we will consider the second revenue scheme. A split up is made between subscriptions (27%) and prepaid cards (73%), taking into account a larger service usage of the first category of users. Finally, the tariff is related to the offered bandwidth: more must be paid for a faster Internet connection. We have added a penalty factor (discount on the tariff) in case the promised bandwidth cannot be delivered by the technology. This only happens when mobile networks are considered for downlink or uplink connection (case 1, 6 and 7).

We assume in all cases a maximum rollout period of five years for the whole network. The bandwidth per user is set at 30 kbps downlink (7.5 kbps uplink). All technical scenarios are evaluated and compared for a 10-year analysis (2008 to 2017) using the NPV method (discount rate of 15%).

**ROLLOUT SCHEMES COMPARISON**

This section focuses in more detail on the effect of the rollout scheme on the overall outcome of the technical cases. We base our analysis on the Belgian railway network. The most important train relations (13 intercity and 14 interregional lines) are taken into account for this paper, covering 1935 km of the 3544 km railway network. Four heuristic rollout schemes are discussed in this section. The purpose of the heuristic models is to obtain a result as closely as possible to the most optimal rollout scheme, with as little simulations as possible. When a fully dynamically allocated rollout scheme would be considered, all 27 train lines have to be dynamically allocated over five rollout years, leading to $5^{27}$ possible rollout schemes, which is not possible to simulate due to model and time limitations.

**Rollout schemes**

Four heuristic rollout schemes have been defined. In scheme 1, we divide the different train relations over a 5 year period based on the number of passengers per relation. The densest relations are prioritized, followed by the other less interesting lines in the next years. This relates to selecting relations with the highest potential of Internet users first. Scheme 2 allocates the train
lines based on their route. We indicate the most important sections in the railway network, which are equipped in a certain year. These sections are ordered and selected based on the number of train passengers passing on these sections. When a relation covers more than 50 km of these predefined sections, this relation will be equipped to offer Internet services. Scheme 3 and 4 are taking into account the interdependencies between the considered relations. The number of km of common tracks between every two relations is calculated, and related to the overall route distance of the relation. The independent relations can be determined, based on the number of dependent relations. We define a dependent relation if the common route distance with an independent relation exceeds 25%. The rollout year of independent relations is selected for scheme 3 according to the number of passengers (same as scheme 1) and for scheme 4 based on specific predefined tracks (same as scheme 2). If the dependence rate for a dependent relation is higher than 75% the relation is rolled out in the same year of their independent relation, if more than 50% in the next year and if more than 25% two years after the relation they depend on.

Best/worst rollout scheme

First we consider the static analysis of our schemes, in which all parameters defining the rollout years of the different schemes were chosen arbitrary. The rollout years are assigned according to the rules discussed in previous section (Figure 1 and Table 1). Large differences can be seen depending on the technical cases. Cases 1, 5 and 7 show for all static schemes a negative net present value (NPV), but depending on the scheme used, a better final result could be obtained. Case 5 could be improved by 3.8 M€, followed by case 7 (2.1 M€). Case 6 even becomes viable. Schemes 3 and 4, which are based on the interdependencies of the train relation, show for most cases an improvement of NPV compared to schemes 1 and 2 respectively.

![Figure 1: NPV rollout schemes comparison](image)

Secondly, a dynamic analysis is executed for the considered schemes, this for optimizing the previously discussed static schemes. We used Crystal Ball, a tool using Monte Carlo simulation to analyze risks, for our dynamic analysis. We let fluctuate some parameters making use of predefined distributions. We ran 25,000 trials for all dynamic schemes. In scheme 1, the
boundaries used for allocating the different train relations, are fluctuated. For scheme two, the year of rollout of the previously defined sections as well as the required number of common distance with the predefined rail sections, are set as assumption values. For scheme 3 and 4, the same uncertain parameters are used as in the related schemes (respectively scheme 1 and 2), as well as the dependency factor, previously set at 25%. The optimization that could be reached making use of a dynamic analysis between the different schemes is smaller than between the static schemes. For case 5, this is still 3.4 M€ (compared to the 3.8 M€ in the static case). The results in Figure 1 show that the dynamic analysis for all technical cases clearly gives better results than the static analysis. For cases 2 and 3 this optimization leads to an improvement of the NPV with 1.6 M€, for case 5 with 1.2 M€. This is mainly in the cases where the rollout years of the predefined sections and the km factor (scheme 2 and 4) are fluctuated.

<table>
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<tr>
<th>(Million Euro)</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
<th>Case 4</th>
<th>Case 5</th>
<th>Case 6</th>
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<tr>
<td>Static (Max – Min)</td>
<td>1.2</td>
<td>0.9</td>
<td>0.4</td>
<td>1.1</td>
<td>3.8</td>
<td>1.3</td>
<td>2.1</td>
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<tr>
<td>Dynamic (Max – Min)</td>
<td>1.2</td>
<td>0.6</td>
<td>1.0</td>
<td>1.0</td>
<td>3.4</td>
<td>1.1</td>
<td>1.8</td>
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<tr>
<td>Max (Dynamic – Static)</td>
<td>0.5</td>
<td>1.6</td>
<td>1.6</td>
<td>0.4</td>
<td>1.2</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Max optimization</td>
<td>1.6</td>
<td>1.7</td>
<td>1.7</td>
<td>1.4</td>
<td>4.6</td>
<td>1.7</td>
<td>2.6</td>
</tr>
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</table>

**Table 1: Schemes comparison**

![Figure 2: Schemes compared to maximum result](image)

When we calculate the maximum optimization that could be obtained, taking into account the static as well as the dynamic analysis, the NPV of all business cases could be improved with at least one million Euros (Table 1). For case 5 the largest improvement could be reached (4.6 M€). This could be explained by the fact that when rollout sequence of train relations and rail network sections are optimized, serious savings could be obtained. Nevertheless the case still stays not viable due to the very large network investments. In Figure 2 the results from the dynamic schemes are compared to the maximum optimized result. From these figures, the best scheme
could be selected for each case. When we only consider one scheme to be used for all technical scenarios, scheme 4 achieves in most cases the best results. For cases 2, 3, 4 and 6 the results for this scheme are situated 4%, 3%, 7% and 0.4% from the maximum optimized result. In all cases except case 4, the best rollout scheme is based on the optimized selection of railway sections.

CONCLUSIONS

We analysed in this paper the effect and viability of different schemes for rolling out an Internet service on trains. A business case is presented based on the Belgium railway network. Seven technical cases were elaborated and compared. We proposed for these cases four heuristic rollout schemes which were compared and evaluated. For the static schemes, large difference could be noticed between the schemes, depending on the case. The results were further improved by using sensitivity analysis on the input parameters in the static schemes. The largest improvement could be obtained for the full dedicated network case. When we only consider one scheme to be used for all technical scenarios, the combination of the interdependencies between train relations and predefined network sections achieves in most cases the best rollout scheme. These results indicate that the choice of a good rollout scheme has an enormous impact on the overall result.

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