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# Techno-economical inspection of high-speed Internet connection for trains

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**Abstract:** Some attractive service scenarios for Railways' Intelligent Transport Systems (RITS) in three different user segments, that is, passengers, freight companies and train operator's in-house customers, are presented. The case study covers the analysis of customer needs and techno-economic evaluations. The analysis indicates that Flash-OFDM technology provides promising pre-stage solution for the train connections in Finland. Also, the WiMAX-based high-speed Internet access for passengers may be profitable in the most heavily operated railway leg in Finland. The sensitivity analysis shows that the most crucial parameters for the case are 'User Share', 'Average Revenue per User' and 'WiMAX Cell Size'. The analysis highlights the large economical potential for RITS services. It is possible, and also recommendable, to implement all the services for different user groups with the same hardware equipment. By this way, investment costs can be reduced noticeably. The in-house customers provide the most attractive service segment in the sense of net present value and reliability, by reducing operating costs and carriage investments while improving the management of operations in general.

## 1 Background

Transportation systems are facing increasing demands in worsening congestion, poor service quality, environment damages, safety requirements and in logistics and interoperability over all regions of the globe [1]. Intelligent Transportation Systems (ITS) is a framework to incorporate information and communications technology to transport infrastructures and vehicles to alleviate these problems and to open up new business opportunities.

The objective of this paper is to inspect and develop some attractive service scenarios for Railways' Intelligent Transport Systems (RITS) by carrying out respective techno-economic analysis, for example, evaluating business scenarios and related technology and inspecting their parameter sensitivities and timelines. Our case studies focus on Finnish railways.

In the analysis of RITS techno-economics, the following components form the business framework:

- *Users*: regular travellers, in-house users and freight (cargo) companies.
- *Service groups*: entertainment, infotainment, advertisements, telemetrics (operation and maintenance of trains and stations), billing and security.
- *Networking solutions*: these are realised by 'ground-to-vehicle communications' (GVC) and 'onboard vehicle communications' (OVC) networking technology (Fig. 1).
- *Customer terminals*: mobile handsets, personal digital assistant and laptops. Terminals must support the investigated OVC technology, for example, WLAN.

The RITS services can be expanded to cover a larger service area than just the train and/or stations that means they could then support heterogeneous networking paradigm enabling a larger number of seamless services. Especially, end-to-end services can then be defined between the starting and destination points of the journey. This enables the design of

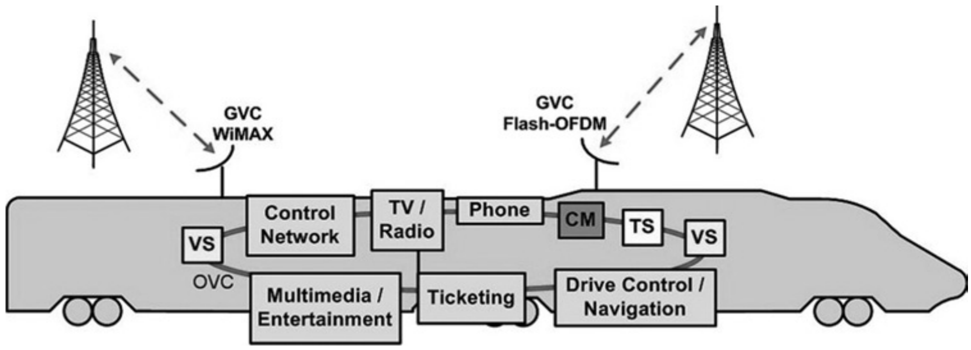


**Figure 1** *Telecommunication networking scenario for trains*
VS, vehicular station; TS, train server

economically and technically tightly connected ITS service portfolio on RITS portal that can be accessed by customer terminals.

## 2 Railways' Intelligent Transport System

### *2.1 Telecommunication architecture*

Telecommunication networking for trains can be divided into backhaul connection, GVC and OVC (Fig. 1). In this study, not much attention is paid to backhaul connection, but it can utilise radio links and the existing fibre optics infrastructure that is built along Finnish railways. GVC comprises the base stations placed near railroads and data links connecting trains to base stations. The OVC network includes customer terminals and 'vehicular stations' placed inside trains. 'Train server' is connected to OVC and 'connection manager' (CM) couples OVC and GVC.

This networking architecture is modular, relatively simple and cost-efficient. It removes customer's need to directly communicate with all the associated networks and enables mobile support of various telecommunication services and customer terminals.

With this networking architecture, support for new GVC and OVC technologies can be easily adapted. Seamless connection to several networks can be achieved by using a CM. It strives to support seamless handovers and multi-homing communications when the train moves in different geographical environments. Thus, multiple access connections can be used simultaneously to enhance the system performance. Also, communication manager supports QoS adaptivity as a function of instantaneous network connection states and throughput demands. This way, each GVC technology is used in the most suitable manner, for example, WLAN in vicinity of stations and mobile WiMAX (802.16e-2005 or HiperMAN) or Flash-OFDM in rural areas. Interested reader is referred to De Greve's discussion of the relating WiMAX with WLAN solution [2]. In addition to WiMAX and Flash-OFDM, the GVC link could utilise satellite connection or GPRS traffic in GSM and 3G networks as done by Icomera and 21Net in Sweden, UK, France and Belgium [3]. However, in our paper, we are excluding the satellite communication option because mobile, high-quality, access of geostationary satellites in Finland is very difficult to arrange economically due to our global northern positioning.

### *2.2 RITS services*

Our analysis is based on splitting the service scenarios basically into three parts: the regular train passengers, freight companies and in-house customers of 'train operator' (TO) (Fig. 2). In this paper, the business case is analysed not only from the perspective of either the regular passengers or the in-house customer [4] but also from the single network investment's point of view. We strive to optimise the overall 'net present value' (NPV) of the telecommunication network investments by taking into account all the customer segments. For passengers, RITS services cover among others Internet connection (making working in train more efficient), travel information services and infotainment. For in-house customers, the connection makes the work of conductors more efficient and helps on maintenance planning of trains and carriages. For freight companies, the real-time connection makes possible the end-to-end ITS and scheduling.

Provision of seamless services has conventionally been in the key design focus of wireless Information and Communication Technology (ICT) system design. However, the availability of the broadband GVC links varies as a function of train velocity and geographical location. Therefore ground-to-vehicle links can usually be continuously used for semi-real-time services only (as for emails and low QoS-multimedia services). Off-line (non-real-time) services of variable QoS can be supported by buffered, on-board train servers that utilise WLAN access networking at the stations only. These services include entertainment, as video and



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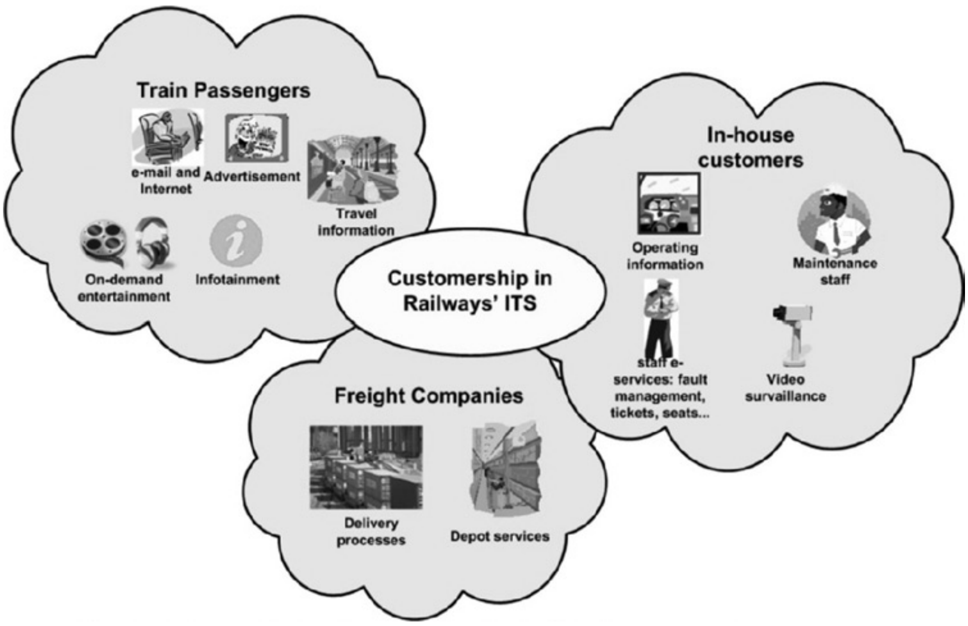


**Figure 2** *Division of customership in railways into three segments*

audio on-demand services as well as monitoring services of on-board telematics in locomotives and carriages. Nowadays, security and safety services are becoming important and the relating equipment costs are simultaneously decreasing. Most of these are well-suited to be supported by the on-board train server because they usually do not require real-time data connections in the GVC link [5]. In order to find an appropriate networking solution, RITS services can be mapped to the respective QoS requirements as shown in Fig. 3.

For each networking technology and service combination, the investment costs should be covered

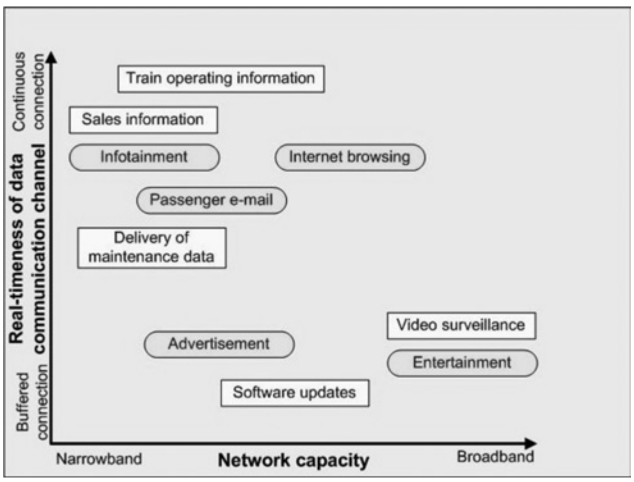


**Figure 3** *Network capacity and real-time service requirements for certain RITS-services*

Rounded rectangles refer to regular passenger services and sharp-edged rectangles to internal customer services

by revenues from services. In general, both the property of seamless connection and the capacity of the network increase the costs. For instance, regular voice calls can be supported cost-effectively using adequate GSM-connection. On the other hand, real-time broadband services generally require expensive broadband networking infrastructure but they might tolerate even drop-outs. Generally, we can note that a great number of services can be realised by a relatively cheap network as analysed in Section 3.

## *2.3 Benefits in different customer segments*

*2.3.1 Passenger segment:* Earnings from passengers can follow several price models:

- Free Internet services: investment paid by increased number of customers.

- Segmentation between first and second-class passengers: on-board data services available in first class only. Investment is paid by increased number of first-class passengers.

- Bundling online services: free on-board data services for passengers buying ticket from the Internet. Service paid by reduced personnel costs. Also, services could be provided free-of-charge for customers buying serial or monthly tickets.

- Advertisements, video and so on, shops: free of charge service for passenger. Data service paid by a third party.



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- Direct revenues: train tickets and data connection are sold separately.

They can be used in parallel and/or their combination may vary as a function of time and number of customers. Application of on-board, fixed installed customer Internet consoles would make the service available for customers having no compatible terminal of their own. In summary, it is a question of knowing the customers, timeline and the service environment in which pricing strategies are applied [6].

*2.3.2 Internal service options:* It has been a typical feature in railways' business dynamics that the level of competition has generally been low. This is due to the assumed superiority of railways' cost structures and efficiency for certain purposes as, for instance, to serve land-based cargo operators. Therefore in railways, there has been a minor focus to track latest development in organisational or infrastructural development. This is the case when compared, especially, with high-tech industries. Hence, the investment level to modern ICT infrastructure has been relatively low. However, this is nowadays rapidly changing and there is an increased requirement for integrated management of transportation modes. Moreover, enhanced follow-up of internal customer's voice, for instance, in development of joint management and data conversion facilities for company's databases is needed. Therefore, satisfaction of in-house user-associated services should be taken as the first step in development of RITS [5].

TO and related collaborative bodies (e.g. transportation companies, banking business and safety authorities) can communicate via this single GVC (instead of a number of different systems) and thus reduce the costs. In [5], the company's in-house services for communication network were discussed. Possible solutions would streamline working, thus reducing the costs directly. Other needs are not directly related to economics but to reliability and safety. One should note that many of the potential applications do not need a high bit rate or a low latency as discussed in Section 2.2. However, when implementing different internal services, the reliability of the network infrastructure must be examined to determine whether the safety requirements are fulfilled or not.

*Conductors' work.* Flexible Internet connection can lighten conductor's work. Nowadays, passengers in Finland buy tickets mainly from the ticketing offices in the stations. Only 5% of the long-distance tickets are bought from the Internet [7]. An important reason for this is the lack of integration of the current online ticketing system. For instance, the checking of Internet tickets is problematic because there is no real-time connection to the ticket sale system. In addition, the checking of credit cards and selling of seat tickets for those who buy tickets in the train is only partially realised. In rural areas, there are no active stations with ticket sale but again conductors sell tickets for passengers. In addition to the checking and selling of tickets, conductors create travel and fault reports. This is nowadays done in trains and reports are then rewritten for electronic form after trips. One solution to this would be laptop computer in which conductor could write the report and transfer it to ground system after trip. However, they could be done in the train all together if there would be a data connection to the land-based systems. The online connection would also make possible to inform conductors about current events such as maintenance and education announcements. In summary, the Internet connection would greatly rationalise the work of conductors.

To estimate the importance of the efficient conductor work, let us assume that 5–10% of the working time can be reduced. This could result, for instance, from increased working efficiency. In addition, 5–10% of the TO's personnel costs are estimated to result from conductors' work, for example, some 5–10% of the staff are conductors [7]. With these assumptions, the yearly savings in Finnish railroads would be 1–4 M€, that is, 2–8% of TO's yearly net profits [7]. If the ticket sales could be moved to Internet, the savings would not be made that much from conductors' work expenses but from the reducing ticketing at stations. Also, this all would contribute to the general service satisfaction: passengers do appreciate fluent e-services overcoming long ticket queues at stations [8].

*Public announcements.* Automatic public train announcements are recorded in CDs and changed manually in all trains when updating timetables [5]. Both of these could be automated by applying RITS communication network. However, quick updates would reserve more transmission capacity than the other information services discussed and the economical savings would be generally quite small. However, the on-line updates would still enable up-to-date announcements that are very important in fault and emergency management.

*Restaurant services.* Restaurant services in Finnish trains use WLAN connections in some stations. The cash system and inventory information are sent to ground systems only when train is stopped at stations with WLAN connection [5]. The number of such stations is relatively low. Therefore currently restaurant supplements are based on earlier experience and do not necessarily follow the actual needs. A real-time communication channel would make this more reliable and it would bring all the restaurant cars to the same tracking condition.

*Communications from locomotive*. Engineman communicates with traffic control using radio phones. Traffic control is partially automated but it could still be improved by using the real-time data connection from train to traffic control systems. This would improve the safety and help to keep the trains on time [9]. Nowadays, in Finland, about 10% of the long distance trips are more than 5 min late [10]. In 2005, Finnish TO paid 70 000€ as compensation for being late. The number of applications were 1500 in 2005 and it has doubled for 2006 [11].

*Maintenance*. Carriages need to be maintained and repaired regularly. This keeps them temporarily out of traffic [5]. Official statistics show that when measured by original purchase prices or using depreciated figures in the end of year 2005, the capital tied in machines was 1670 M€ and 880 M€, respectively [7]. Over half of these figures stand for locomotives and carriages. Nowadays, the maintenance staff does not know the location or general condition of carriages in real time. Therefore pit stops cannot be predicted and prepared. This makes the work at depots inefficient and locomotives and carriages must wait for nothing. Real-time connection from trains to ground systems would make the work more efficient and the number of railroad cars could be reduced. We can estimate that 1–5% of railroad cars could thus be written down (i.e. sold or making smaller car investments). This is worth of 5–50 M€ (10–60% of TO's net profits) depending on whether old equipment is actually sold or new investments are realised. This is nearly the same as WiMAX network investment costs covering all the electrified railways in Finland (Section 3.2.2).

*2.3.3 Freight:* Cargo traffic in Finnish railways yields about the same amount of revenues as passenger traffic [7]. The latter is, however, highly subsidised by state of Finland, and in reality, cargo traffic is much more profitable.

End-to-end ITS can be used efficiently in cargo business also. For example, accurate cargo monitoring is possible when the ITS covers company's whole delivery process. According to Aberdeen Group [12], companies using supply chain management system are three times more likely to have faster delivery times than the companies that have not adopted the solution – by reducing the amount of manual work. Real-time information about relating transitions would be useful and would offer new business opportunities for railway operator and transport companies in general.

### 2.4 Passengers' attitudes on RITS services

We have run a survey for train passengers concerning common Internet services [13]. Random sampling was used for two different passenger groups. The actual target group, that is, the train passengers with laptops, represented 70% of the total sample of 167 passengers. The rest 30% (i.e. 50 respondents) were other potential users, including the passengers owning a laptop but carrying it rarely or never with them. Non-laptop respondents were randomly selected from among the all non-laptop-passengers. It is worth noticing that the percentage of laptop-owning passengers was not studied in the survey since it would have meant to make survey in every turn in 1 day.

The survey clearly indicated that there is a high demand for RITS services. Most of the laptop users (86%) travel in the train at least once a month, and over half (55%) at least once a week. High number (87%) of passengers in this group use laptop at least every now and then while travelling, and 71% almost in every journey. Nowadays, GSM and 3G communication from the train is supported by using repeaters in trains.

When laptop passengers' opinions were asked about their willingness to use ICT and RITS on-board services, wireless Internet connections were seen important practically without an exception (Fig. 4). Need of RITS services is confirmed also by other passenger surveys as for instance by [5].

## 3 Techno-economic scenarios for passenger services

Let us now consider the techno-economics of RITS in Finnish railways by searching the answers for questions of how to invest in RITS and what would be the most important risk to watch out when focusing on passenger segment. Here we first analyse a two-stage railway communication services in Pendolino trains between Helsinki and Tampere. This route is selected due to the fact that it carries the largest number of passengers between the two largest city areas in Finland. In our business scenario, the first stage is to establish the OVC network and to apply (i) EGPRS/UMTS and (ii) Digita's Flash-OFDM Network for GVC networking. The second stage upgrades the GVC by WiMAX networking in 2009. After that some expanding options are considered.

### 3.1 Case: Pendolino trains at Helsinki–Tampere route

Consider Finnish Pendolinos in the track between Helsinki and Tampere. The length of this route is ∼200 km. The overall number of daily trips in this route is ∼20 000 [10]. We estimate that 15% of these trips would be travelled in Pendolino trains. Some 27% (19 out of 70) of daily turns between Helsinki and Tampere run with Pendolino trains, but the number of



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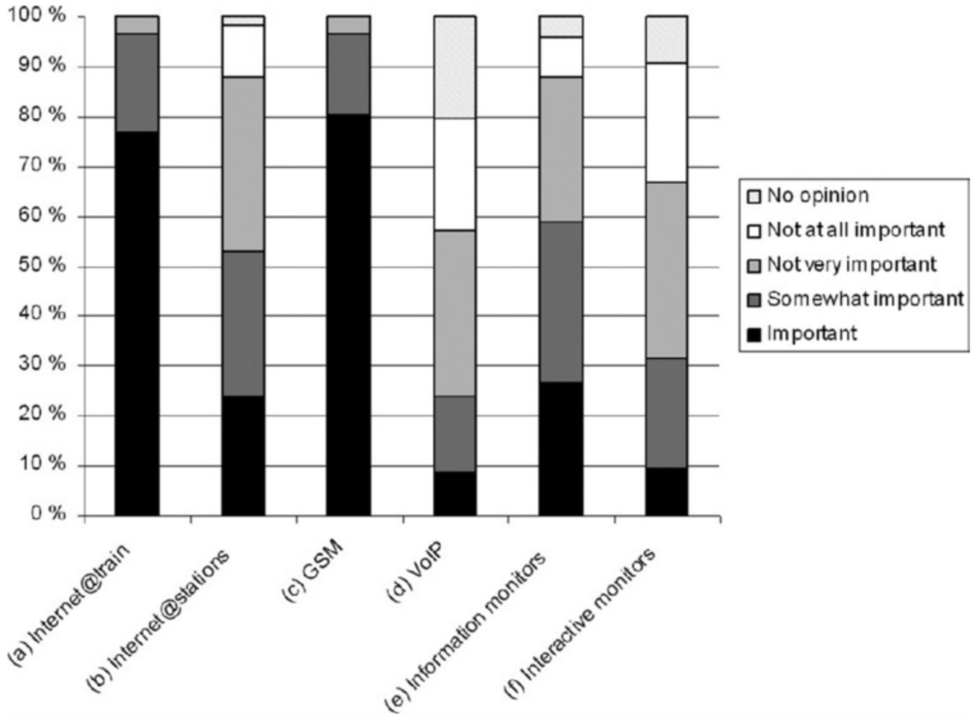


**Figure 4** *Study of passenger's attitudes in Finland for various RITS services [13]*

The darker the bar the more important the service is for the interviewed customers

Assigned questions were: (a) availability of wireless Internet connection in trains, (b) availability of wireless Internet connection in stations, (c) improvement in GSM reception, (d) availability of VoIP (calls through Internet), (e) topical information (as route assistance) through the on-board info monitors and (f) monitors equipped with touch pads for the use of train travellers

seats in Pendolino is smaller than that in Intercity trains [14]. Moreover, we estimate that currently 20% of the Pendolino users are equipped with WLAN-enabled terminals or are otherwise potential subscribers for the services. We assume that the amount of potential customers increases some 5% a year. The rate is two times the rate growth of all railroad trips. This is partly due to the fact that more laptop users choose Pendolino when there is network connection. We assume that the adoption of network services among laptop users follow Fisher-Pry model and is at level 10% in the beginning and grows to 50% in 2 years [15]. These estimates and assumptions would then mean that the number of subscribers per day would follow the calculations shown in Fig. 5. It is interesting to note that already realised Icomera's RITS-services for X2000 trains in Sweden have 4000 daily subscribers out of all the 70 000 daily passengers [16].

We define the concept of 'throughput demand' to describe (i) statistical distribution of user traffic and (ii) the limited networking capacity. To estimate it, let us assume for a worst-case scenario that the current service rates for an end user are 512 kbps for downlink (DL) and 256 kbps for uplink (UL). Practical values may for some services be considerably smaller. With an overbooking factor of 13, the average DL throughput per user would be 0.04 Mbps and half of it for UL. If we estimate this to grow 20% annually, the total DL demand for users would grow as shown in Fig. 5. Note that actually the daily users are not served simultaneously. Thus, in calculations shown in Fig. 5, the users are evenly distributed over 19 daily turns.

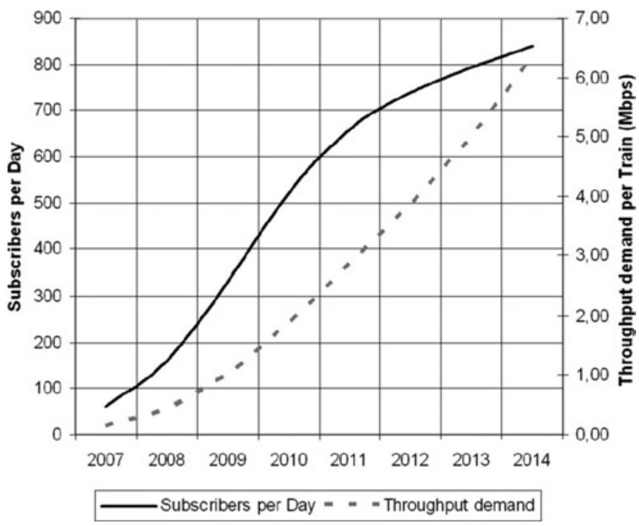


**Figure 5** *Estimated number of daily subscribers and throughput demand in one train for the new information services in Pendolino trains between Helsinki and Tampere*

*3.1.1 Costs of the OVC networks and Flash-OFDM subscriptions:* Let us consider the OVC network and the management of the services. One management unit, that is, a train server and a CM, and six WLAN base stations are constructed per train, which can be Pendolino or some other train.

GPRS traffic in 3G (EDGE or UMTS with HSDPA) networks could be effective starting and backup channel for GVC link. Currently, the mobile operators' networks provide EGPRS (GPRS in EDGE network) between Helsinki and Tampere, but UMTS network is up in urban and suburban areas only [17]. This means that only 236 kbps data rates can be assured for whole the route and some 2 Mbps DL data rate for urban areas. However, the technology is developed for mobile use and works reliably within Pendolino speeds. In addition, the capacities will grow in the future.

Digita is deploying Flash-OFDM network in Finland [18]. Currently, the network covers the whole route from Helsinki to Tampere. TO could be a customer of Digita and use the network at least in the early phase of RITS services. Flash-OFDM works quite well for the maximum speed up to 200 km/h that is used by Finnish Pendolinos [19]. Service operators in Digita's network offer 1 Mbps (DL)/512 (UL) data rates. This may meet the demand of some 20 users per train in the year 2008 – see the subscriber and demand forecasts (Fig. 5) – even if the travellers are not evenly distributed for the 19 daily Pendolino turns between Helsinki and Tampere [14]. Moreover, the offered data rates may rise in the future, since the current frequency band is only 1.25 MHz frequency division duplexing.

The equipment costs, installation costs and network operating costs are summarised in Table 1. Flash-OFDM and GPRS operating costs include the subscription fees (70€ and 30€ per month) and possible costs of using the subscription. With the values given in Table 1, the investment – with Flash-OFDM or GPRS – would be 2900€ per train. If the maintenance costs are assumed to be 20% of the investment, the overall operating and maintenance costs would be some 3500€ in a year per train for Flash-OFDM and 3000€ for GPRS. This means that the service would become profitable if each train providing it gains profit 10€ a day, after marketing and billing expenses that depend on the revenue strategy (Section 2.3.1). In summary, Flash-OFDM and GPRS are economically comparable, but due to the lack of UMTS coverage in rural areas Flash-OFDM seems to be more suitable than GPRS in our case.

**Table 1** Cost structure of OVC network, Flash-OFDM and EGPRS components

| | Price | Installation costs | Operating costs (per year) |
|---|---|---|---|
| EGPRS/UMTS | 300€ | 100€ | 500€ |
| Flash-OFDM | 300€ | 100€ | 1000€ |
| Management unit | 2000€ | 2000€ | 1600€ |
| WLAN base station | 100€ | 150€ | 50€ |

*3.1.2 Costs of the WiMAX network:* Based on our traffic intensity predictions, GPRS or Flash-OFDM network cannot provide sufficient data rates for route Helsinki–Tampere after 2009 (Fig. 5). Instead, mobile WiMAX seems to be a promising option to fulfil the predicted demands. Based on the methods in [20, 21] and analysis in [20–26], we now inspect the cost structure of WiMAX network and investments in 2008–2009.

The coverage radius of the mobile WiMAX base station is estimated to be some of 5 km with 10 MHz bandwidth and 3.5 GHz centre frequency. Depending on the channel state, terminal speed and modulation techniques used, the data rates can then be predicted to vary from 3 to 5 Mbps [22, 23]; see Table 2 for mobility comparison of analysed technologies. Notice that the terminal speeds, data rate capacities and coverage areas are more or less related to each other and improving one may weaken other parameters. The last column in Table 2 estimates the practical data rates in Finnish railways when using Pendolinos up to speeds of 200 km/h. The estimated DL data rate of 5 Mbps and UL data rate of 3 Mbps for WiMAX provides answer for throughput demand in our case (Fig. 5). One should note that currently WiMAX does not support vehicular speeds over 120 km/h [24]. However, a standardisation work group 802.16 m is specifying a backward compatible amendment to WiMAX to enable support for mobile terminals moving up to 350 km/h [25]. In addition, Nomad Digital has modified the WiMAX protocol to support this, enabling a WiMAX hybrid to be used in high-speed trains [26]. However, protocol modifications may result in incompatibility issues with standard WiMAX-equipment.

The WiMAX costs follow exponential curves with the parameters of Table 3. The prices of WiMAX components are estimated using the fixed WiMAX component prices. New pylons are not built, but the operating costs for base station include the site rental costs. The OVC components (e.g. management unit and WLAN base station) are already implemented in

**Table 2** Estimates for functional mobility speeds and data rates for different technologies

| | Max terminal speeds, km/h | Max DL data rates, Mbps | Estimated data rates (in Finnish Pendolinos) |
|---|---|---|---|
| Flash-OFDM | 250 | 5.3 | 1 Mbps (DL)/512 kbps (UL) |
| EGPRS | 250 | 1 | 236 kbps (DL, UL) |
| UMTS/HSPA | >250 | 14.4 | 2 Mbps (DL)/1 Mbps (UL) |
| 3G LTE | 350 | >100 | — |
| 802.16e-2005 | 120 | 70 | 5 Mbps (DL)/3 Mbps (UL) |
| 802.16 m | 350 | >100 | — |

the first stage of the investment but the WiMAX transceiver must be purchased. In calculations, all the OVC operating and maintenance costs are bundled with WiMAX transceiver costs. To estimate the yearly maintenance costs, the amounts of components installed are multiplied by maintenance factor 0.2 and the component prices at a time. However, in the beginning, the maintenance factor is 0.1 and it grows to 0.2 during the first 2 years. Estimation of maintenance costs is anyhow not critical due to the fact that in overall costs the maintenance forms only a small fraction in any case.

The resulting cost structure for the considered 7 operating years in the case of Helsinki–Tampere connection is shown in Fig. 6. The investment costs are 1.0 M€, which is about 0.3% of the Finnish railway's passenger traffic revenues (320 M€ in 2005 [7]). In summary, we can conclude that the investment costs have a major effect in the total cost structure (2.7 M€).

*3.1.3 Revenues and profitability:* New revenues from passengers are evaluated using the estimated number of users (Fig. 5). The average revenue per user is assumed to be 3€. This can in some cases come directly from the passengers, but the revenues may also be gathered indirectly (e.g. advertisements or more first-class passengers; Section 2.3). The billing and advertisement costs of the new services are not considered here, since they are greatly related to the revenue strategy and should be optimised within it. The WiMAX phase revenues are depicted in Fig. 6*d* and total revenues in Fig. 7. In Finnish taxation, the tax rate is 26% and the depreciation times we use for network components are 5 years. By these assumptions, the yearly profit of the service is positive over the period 2007–2013 (Fig. 7). The first 2 years with Flash-OFDM are really profitable (NPV 0.2 M€) and the NPV of the WiMAX network with 15% discount rate is 0.1 M€. However, to achieve reliable network connection, the first stage subscriptions (Flash-OFDM) are continued and used if needed simultaneously with WiMAX connection. Over the whole period from 2007 to 2013, the discounted cash flow (NPV) for communication services is 0.3 M€. The business case seems to continue profitably, but new technology considerations have to be done in 2012 or 2013, that is, upgrade to coming WiMAX evolutions that are compatible with the existing standards. This is relatively cheap because of the modular architecture of RITS (Section 2.1).

*3.1.4 Sensitivity analysis:* Subscribers' share was assumed to increase during the study period from 3% to 4.5% of all the passengers in the considered route (i.e. 20% to 30% of Pendolino travellers). If these are decreased by 10% (i.e. 18% and 27%), the NPV of the WiMAX investment becomes negative. The same occurs if the average revenue per customer is decreased by 10% to 2.70€.

**Table 3** Cost structure of network components. This table is based on the prices of fixed WiMAX network [21]

| | Current Price | Development | Installation costs | Operating costs (per year) |
|---|---|---|---|---|
| Spectrum license | — | — | — | 10 €/km$^2$ |
| Radio link | 25 000€ | 0.90 | 2000€ | 2400€ |
| WiMAX base station | 10 000€ | 0.85 | 4000€ | 1800€ |
| WiMAX sector | 7 000€ | 0.85 | 500€ | 1200€ |
| In-train components | 3 000€ | 0.85 | 3000€ | 2000€ |
| WiMAX transceiver | 400€ | 0.80 | 100€ | 100€ |

 

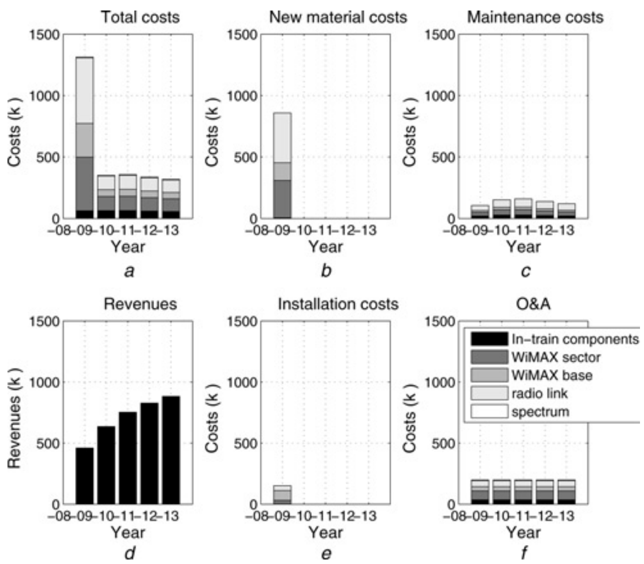


**Figure 6** *Cost structures and revenues for the mobile WiMAX-based services in route Helsinki–Tampere*

In Fig. 8, the NPV is plotted as function of revenues, WiMAX costs or WiMAX cell range parameters. The WiMAX network component parameters do not have as great effect as revenue parameters. However, the range of the WiMAX cell is important. If the cell range is decreased by 10% to 4.5 km, NPV becomes negative.

## 3.2 Expansion and new business options

*3.2.1 Expanding to all trains in route:* In this paper, we focus on Pendolino traffic between Helsinki and

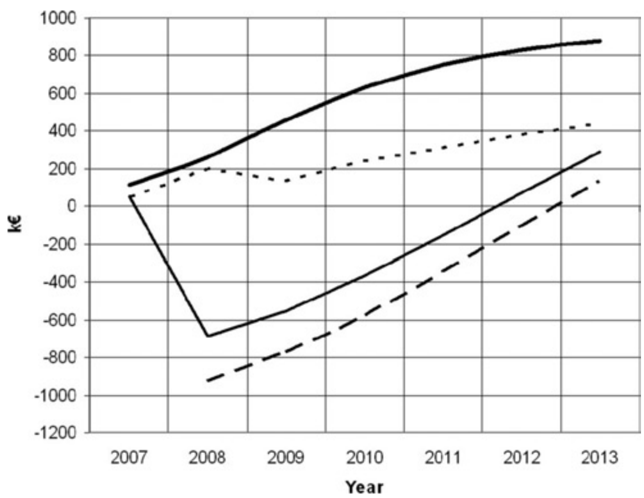


**Figure 7** *Revenues (thick solid curve), yearly profits (dotted line) and the discounted cash flows of the WiMAX phase (dashed) and whole project (narrow solid curve) of the new information service offered for Helsinki–Tampere Pendolino travellers*

Network component prices follow Tables 1 and 2

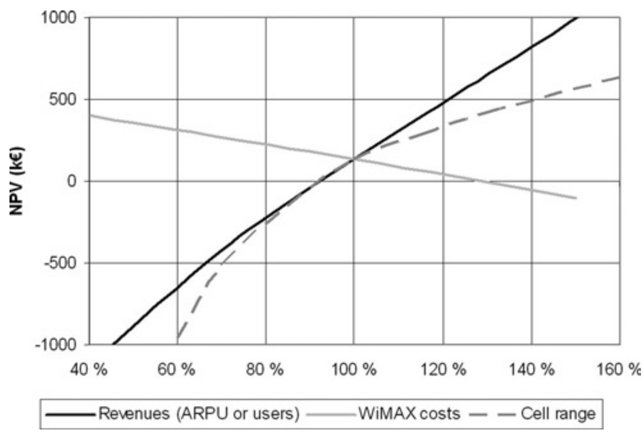


**Figure 8** *Sensitivity analysis of the WiMAX solution for passengers' communication service*

Tampere because more than half of the long-distance train trips use this route in Finland. Since the network coverage plays a significant role in the network investment, the created GVC capacity can be used by non-Pendolino trains too. The Finnish TO has 722 passenger carriages [27] and operates overall 70 daily turns that use the route Helsinki–Tampere [14]. If the share of laptop customers is assumed to grow steadily in years 2007–2014 from 10% to 15% of all the passengers, the overall network investment with GVC and OVC parts would be 3.0 M€ and the NPV of the 7-year study period would be 1.0 M€. The NPV would be positive even if the average revenue per user was assumed to be 2.50€.

*3.2.2 Covering the railway network:* One option is to expand the service over all the Finnish electrified railways. The overall length of electrified railways that are used in passenger traffic is ~2800 km (i.e. 50% of all Finnish railways) [27]. The traffic in rural areas in the non-electrified railways is currently non-profitable and there is a significant subvention by the state. However, because the tickets in these areas are sold by conductors (since there are no active stations), the real-time communication channel is of great use for ticketing and checking the billing. This strives for the Flash-OFDM solution there. The amount of trips outside the capital region in Finland was 12.2 million in 2005 [7]. If it is assumed that 10% of these trips do not use electrified railways, the daily traffic in our case would be 30 000 trips. As analysed earlier, the Flash-OFDM would be sufficient and profitable solution for all the trains. However, the coverage is currently low and later the capacity (1 Mbps/512 kbps) may become restrictive. The WiMAX solution over Finnish electrified railroads would yield investment costs of 15 M€ and NPV −15 M€. This is 35% of the net profits of 2005 for the TO. However, the network investment costs could be spread over several years, if the network is built in



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two or more phases. These investments are paid back quickly if the forecasted in-house customerships and savings are realised (Section 2.3.2). The dimension of the investment in Finnish electrified railways can be compared with the communication network investment by Icomera for SJ in Sweden. That contract – covering about 2000 km and 85 trains – was worth of 11 M€ [16, 28].

*3.2.3 New business opportunities:* The Internet connection offers a new business environment in trains. Entertainment, infotainment and electronic shopping can be utilised to yield new revenues as well as to create a modern brand to support further amplification of the business case. Some of these services can be accessed by using the train server (that is, a rugged, on-board PC serving as a data connecting hub and a data storage unit). In addition, the on-board service terminals with touch screens can be installed in trains to offer the RITS services for all the train passengers.

An interesting extension to communication services in domestic long-distance traffic would be the international traffic, especially the route between Helsinki and St Petersburg [29]. The passengers, as well as personnel, goods traffic and customs would benefit from this communication services.

# 4 Summary

We have discussed a train data communication system and associated services. In addition, we have made some techno-economical inspections of GPRS, Flash-OFDM and WiMAX-based high-speed Internet connections for the most heavily operated railway section in Finland, that is, for the railway track from Helsinki to Tampere. The overall techno-economical implementation was also addressed. We noticed in our analysis the large economical potential of RITS services. Also, benefits culminate to cost savings and making of TO's operations more reliable and efficient.

Although the overall costs of the mobile WiMAX network covering Finnish electrified railways were estimated to be as high as 15 M€, by combining the revenues and savings from passengers, freight companies and in-house customers, the pay-back period of the investment would only be few years. Our studies indicate that – from all the introduced service categories – the in-house services seemed to be the most important ones. Therefore significant economical benefits can be acquired through the development of in-house activities with ICT. For example, the streamlining of the planning of truck and carriage maintenance by using an automated collecting system of faults, location and kilometre information would make the use of railroad cars more efficient and indeed covering the communication network investments. Also, the benefits in streamlined ticket sales and conductors' work would generate 1–4 M€ yearly profits. Thus, the TOs should concentrate on monitoring the change of in-house economical indicators when considering the investment and operational costs of train data communications systems.

NPV of passenger's e-services are noticeably moderate. For opening the communication services – as the amount of users and the demand for throughput is moderate – currently available Flash-OFDM technology is a promising offer for GVC network. It is profitable when daily revenues as low as 10€ per train is achieved. The investment costs for mobile WiMAX network in the route of Helsinki to Tampere would be 1.0 M€. If the RITS service is provided for Pendolino trains only with Flash-OFDM as pre-stage and WiMAX network after 2008, the NPV of the project with 3€ ARPU during the 7-year period would be 292 000€. However, WiMAX (IEEE 802.16e-2005) currently work only up to 120 km/h, although Finnish Pendolinos use speeds up to 200 km/h. The sensitivity analysis shows that the share of potential users (assumed to grow from 20% to 30%), ARPU (3€) and the cell range of the WiMAX network (5 km) are the most critical parameters in this case. If any of these values is decreased by 10%, the NPV would still be positive.

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