

TECHNO-ECONOMIC EVALUATION OF INTERNET SERVICES ON-BOARD TRAINS

VAN OOTEGHEM, Jan

NAUDTS, Bram

LANNOO, Bart

VERBRUGGE, Sofie

COLLE, Didier

PICKAVET, Mario

¹ *Dept. of Information Technology (INTEC), Ghent University – iMinds,
Gaston Crommenlaan 8 bus 201, 9050 Gent, Belgium*

Email for correspondence: jan.vanooteghem@intec.ugent.be

ABSTRACT

Internet services on-board of trains are being deployed worldwide. A single (passenger focused) service is in most cases not sustainable due to large costs and often disappointing revenues. Running new applications over the same infrastructure to increase revenue is therefore essential for current and future deployments to become sustainable yet current techno-economic models suffer from several limitations or complexity to analyse this case. In our research we integrate technical, social, economic and business components to quantitatively estimate the viability of Internet services on-board of trains. An Excel based tool has been built, taking into account technical (railway infrastructure, service requirements such as bandwidth, availability of technologies for train-to-wayside communication), economic (costs and revenues) and business parameters (actors involved, business models, multi-actor allocation schemes). A case study for Belgium has been worked out to show the capabilities of the model.

Keywords: Internet services, trains, techno-economic evaluation

INTRODUCTION

Internet services on-board of trains are being deployed worldwide. On-board Internet services such as passenger Internet should prove to be a revenue source for operators however often a positive business case cannot be realized due to a high total cost. The introduction of new services that run over the same communication network will determine the future success of on-board Internet services.

Each type of railway application - like passenger information systems, ticketing, remote train control, Internet service, etc. - has their specific requirements (quality of service, delay, bandwidth, etc.). Prioritizing the applications is of utmost importance and an assessment must be made in terms of performance (e.g. uptime of the service depending on network availability, bandwidth consumption) and cost/benefits (equipment and operational costs, process optimization and cost savings, additional revenues).

Only focusing on pure Internet connection on-board of trains will not make the business case. This has been seen in previous and current deployments across the world. Since 2003 different trails and deployments have been set up, mainly throughout Europe and North America on long distance lines (e.g. SNCF in France, SJ in Sweden, VIA Rail in Canada, Amtrak in USA, Thalys in Belgium/France), where in the beginning, most focus was put on offering only passenger services. Therefore more focus should be put on additional value generating services for passengers such as video on demand (VoD) or tourist information, but most importantly on crew and train services such as Voice over IP (VoIP) communication, Closed Circuit TV (CCTV), online ticketing, machine-to-machine (M2M) communication, etc. This last category of services will improve and optimize the operational processes for the different actors involved (train operator, maintenance companies, train constructing companies, etc.), and can result in a sustainable opportunity for cost savings, making the overall business case viable. Leading companies today offering a range of services onboard trains are Nomad Digital [1], Icomera [2] and Nokia Siemens Networks [3]. Different scientific studies have been conducted related to the economic viability of Internet based services onboard trains, mostly starting from a technical point of view, proving that it is difficult to run a business case upon one single service [4][5][6][7].

Different actors are involved in the value network when offering railway services ranging from train operating, maintenance and constructing company over integrators, service and content providers to passengers, crew and on-board equipment. Each of them also have different goals (such as increase of profits, better service delivery, process and cost optimization, efficiency gains), so the overall viability of the business models and the individual actor performance needs to be considered, in order to have a sustainable solution. Most railway and train operating companies are run and financially supported by public authorities promoting public transport. Future investments and innovation in new infrastructure and services is required to attract more users while at the same time budgets are tight. Therefore, a clear overview of potential savings and new revenues should be high on their agenda.

An Excel based tool has been built, taking into account technical (railway infrastructure, service requirements such as bandwidth, availability of technologies for train-to-wayside communication), economic (costs and revenues) and business parameters (actors involved, business models, multi-actor allocation schemes) in order to quantitatively evaluate the economic viability of Internet services on-board trains. In the upcoming sections we will go more into detail on the different aspects of the model such as the railway network, telecommunication network technologies considered, services to be offered, cost/benefit

model and multi-actor analysis. A case study for Belgium has been worked out to show the capabilities of the model. We will conclude this paper with recommendations and future work.

RAILWAY NETWORK

The railway network can be modelled based on the geographic coordinates of all stations. The distance between two directly connected stations is calculated as a straight trajectory. This model is used to map the real trajectory of a train between two stations to the railway network. The data about each trajectory can be enriched by adding the train frequency for each trajectory per day and by an estimation of the number of passengers. Next the configuration of the rolling stock on each train line and a mapping to their trajectory can be included. Extra parameters can be added such as the number of cab and slave cars (in order to calculate the on-board installation costs), number of seats per train car and the occupancy rate. Other points of interests such as the location of cross roads, working places and cleaning rooms are also taken into account. These parameters are required by the model in order to calculate the total demand for bandwidth (see service section).

ACTORS

Different actors are involved in the value network when offering railway services ranging from train operating, maintenance and constructing company over integrators, service and content providers to passengers, crew and on-board equipment. Each of them also has different goals (such as increase of profits, better service delivery, process and cost optimization, efficiency gains), so the overall viability of the business models and the individual actor performance needs to be considered, in order to have a sustainable solution. In many cases train operating companies are not interested in operating an “Internet on-board service” for passengers as their main business is transportation of people or cargo. So often there are other actors involved. The most important actors are:

- Train operating company (TOC): the entity that operates the trains for passenger and/or cargo transport.
- Train constructing company (TCC): manufactures trains to be sold to TOCs. They are especially interested in monitoring of new delivered trains (related to warranty period and potential technical issues).
- Train maintenance company (TMC): maintains and repairs trains (in most cases part of the TOC)
- Railway infrastructure owner (RIO): operates and maintains the railway network infrastructure including stations, working places and cross roads.
- Network operator (NOP): provides train to wayside network access to the train.
- Integrator (INT): a company that brings together component subsystems and ensures that those subsystems function together.
- Service provider (SP): offering services to end customers (can be passenger, crew, TOC for diagnostic data).
- Content provider (CP): an organization that creates informational, commercial, educational or entertainment content that will be accessible on the train.

- End users: the train itself (as data will be sent from and to the train for monitoring, by machine-to-machine communication), the train crew (driver, conductor and other personnel such as safety guards, bar keepers, etc.) and train passengers

TECHNOLOGIES

Types

The different available outdoor technologies can be grouped into terrestrial and satellite networks. The first category is often split in two subgroups: mobile networks and wireless data networks although the boundaries between these two categories are fading. In the following subsections, the different outdoor technologies are briefly discussed.

The primary requirements of mobile network technologies were initially limited to good coverage and high mobility rather than high bandwidth. Important radio access technologies of this category are GPRS, UMTS, HSPA and E-UTRA.

GPRS introduced packet-switched networks for mobile data traffic with low downlink and uplink data rates. UMTS (often referred to as 3G), which has been specified as an integrated solution for mobile voice and data, uses the same core network as GPRS, but requires a new access network [8]. HSPA is the successor of UMTS with increased data rates [9]. E-UTRA (often referred to as LTE or 4G) is a wireless data extension of UMTS technology and the proposed successor to HSPA, but is not considered in our model [10].

Wireless data network technologies have been used as dedicated trackside solutions, consisting of a series of base stations along the tracks. Wi-Fi and (the mobile version of) WiMAX are the most used technologies as wayside network solution. Wi-Fi is a wireless local area network (WLAN) technology based on the IEEE 802.11 standard. The most popular 802.11b, 802.11g and 802.11n protocols use the 2.4 GHz band [11]. Mobile WiMAX, specified in IEEE 802.16e, operates in the 2-6 GHz band, which is developed for mobile wireless applications, and has a larger range than Wi-Fi. Both technologies can support large bandwidth capacity [12].

Satellites usually have a large footprint, which means that they are visible from within a very large geographical area on earth. This makes them very suitable for train connections. A drawback is the required line-of-sight. Data rates for downlink and uplink depend the standard (Ku or Ka) where the bandwidth capacity allocation is either fixed or dynamically, respectively.

Table 1 indicates the technical parameters (range of the base station, theoretical maximum forward, to the wayside ($>W$) and return, to the train ($>T$) bandwidth) of the described access technologies, as well as the considered number of base stations required for a wireless network to cover a new area. As the theoretical bandwidth (or throughput) is not always reached (depending on number of users in the area, time of day, etc.) we only consider for the evaluation model half of the presented bandwidth ($>W$ and $>T$) for the mobile networks. WiFi, WiMAX and Satellite are dedicated technologies chosen for the service and can thus offer the full network capacity. For the first two technologies, we consider a bandwidth lower than the absolute theoretical throughput due to the fast moving character of the train.

For the placement of additional base stations, we consider the following number, depending on the type of location (based on the area that needs to be covered) and current availability of technologies: stations (3), working places (5), cleaning rooms (1) and cross roads (2).

Table 1: Technology parameters for mobile, wireless and satellite networks.

Range and Bandwidth						
	GPRS	UMTS	HSPA	Wi-Fi	WiMAX	Satellite
Range (km)	3	1,5	1	1	3	
FWD bandwidth (in kbps)	56	384	1800	6000	6000	2000
RTN bandwidth (in kbps)	18	128	384	1500	1500	500

Number of BS per location						
	GPRS	UMTS	HSPA	Wi-Fi	WiMAX	Satellite
Station				3	1	
Working places				5	1	
Cleaning rooms				1	1	
Cross roads				2	1	

Availability

It is often impossible or too expensive to cover the railway network with a single technology. The best technical choice highly depends on the type of area where the track is located and often a mixture of technologies is used. Mobile networks do have the overall best coverage, certainly in urban environments, but problems can occur when tracks are embedded in the landscape. Satellite networks have a large footprint and are best used in more rural areas but line of sight cannot always be guaranteed (e.g. when the train is crossing a tunnel, or in dense populated areas). A solution is the installation of a dedicated wireless network (e.g. WiFi or WiMAX) at dark spot locations. These technologies can also be used in locations where large bandwidth capacity is required but are expensive to deploy. We have foreseen in our model a standardized set of parameters for modelling technology availability. An overview of our considered parameters is shown in Table 2.

This information can be furthermore optimized when real life network measurements are available. An example can be seen in Figure 1 and Figure 2 where network coverage measurements have been carried out, related to base station locations and maximum throughput is calculated for a specific track (Antwerp – Ghent) [13].

Table 2: Technology availability considered per location

Technology Availability (standard parameters)						
	GPRS	UMTS	HSPA	Wi-Fi	WiMAX	Satellite
Along the trajectory	90%	75%	50%			80%
Stations	90%	90%	75%	50%		60%
Working places	90%	30%	30%			
Cleaning rooms	90%	30%	30%			
Cross roads	90%	75%	50%			80%



Figure 1: Network availability on the Antwerp-Ghent trajectory

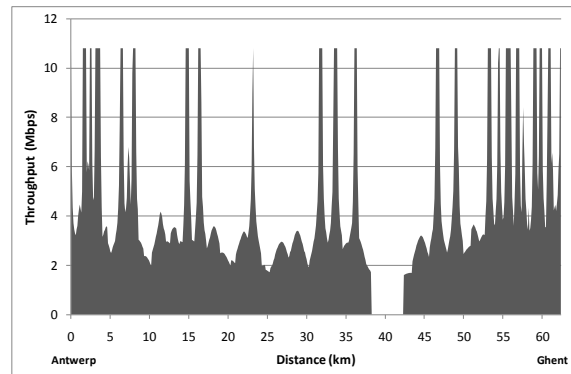


Figure 2: Maximum throughput along track Antwerp-Ghent.

SERVICES

Types

We selected three categories of services based upon level of priority. The 'vital control data' consists of services that relate to critical diagnostics (monitoring train diagnostics, localization via GPS, crew communication, remote train preparation). A second category includes 'event-driven and crew services'. These services have a supportive function towards the crew and will lead to an increased efficiency and safety (improved crew communication, drivers' assistance system, passenger counting, advance hazard warning system, CCTV on-board). The third category of services is 'passenger services', offered to entertain, inform and please the passenger along the journey (travel information, infotainment, seat reservation, advertising and 'Internet-on-train' access for the passengers). These services are detailed in the next paragraphs with indication of the potential benefit for each actor.

Vital control data

- *Localization based on GPS coordinates:* the exact position of the train is frequently sent (every 20 to 30 sec) to the wayside, to trace potential problems or train delays (important for the TOC, to be used for internal operations and real time info to the passengers).
- *Critical diagnostics:* the continuous monitoring of critical parameters in the train (e.g. train breaks, motor information, air conditioning, etc.). When severe issues are monitored direct actions could be taken (e.g. maintenance in next station, remote restart of processes). This will result in an overall better state of the fleet (larger number of operational trains and carriages, thus requiring less orders) (benefit for the TOC) and better maintenance schedule of the equipment stock (TMC). Monitoring new delivered trains by the TCC is also important for warranty purposes and potential problem solving [14].
- *Remote train preparation:* trains could be started up from the control centre. This way early stage problems could be detected and solved before the train will be operational

(TOC benefit). When software and driver updates could be done remotely, large time savings could be gained by the INT (currently performed manually by USB stick train by train).

Event-driven and crew services

- *Automated Driver Performance Monitoring (ADPM) / Driver Assistance System (DAS)*: this service is designed to support the train driver to alter the speed of the train in the most eco-efficient way. Real-time data about the trajectory, timing and driver behaviour is required, in order to give the correct directives towards the driver in order to minimize energy consumption, leading to a overall substantial cost saving. This service will also reside in an overall greener image of the train operator company (TOC), less damage to the train and improved safety.
- *Passenger counting*: currently the expected number of passengers in stations is calculated based on ticket and subscription sales figures and manual counting. More accurate figures could be obtained when passengers would be counted when getting in or out the train (improved system for the RIO). This is used to optimize the required number of carriages, marketing purposes, etc. for the TOC.
- *Advance Hazard Warning System (AHWS)*: annually about 50 accidents happen with vehicles and 6 accidents with pedestrians on railway crossings in Belgium. Infrabel, the Belgian railway infrastructure owner (RIO), has set up an action plan for 2008-2015 to limit the number of crossings, to increase prevention with the introduction of cameras, to introduce safety improvements, etc. When camera information would be sent to the train at a kilometer distance from the crossing, an emergency break would be possible to stop the train safely, or at shorter distance sound an alarm.
- *CCTV on-board*: the installation of a CCTV system on-board has many advantages such as increasing safety of passengers and crew. It is practically impossible to monitor and send all images always from the train to the wayside. Several options are possible and can be combined: data offload every night at the train depot, low resolution video sent to the wayside and high resolution stored on-board, event-driven video communication, etc. In our model, we opt for the last possibility thus event-driven communication when an alarm is activated by a passenger or crew member, or when a specific event is detected by a camera.
- *Crew communication*: a full coverage service with no delay must be offered for communication between the wayside and crew members on-board the train, besides the current GSM-R network connection.

Passenger services

- *Up-to-date travel information*: In order to reduce the number of complaints by customers about delays or abolished train connections, strikes or other special events, a real-time travel information service on-board the train should be offered [15].
- *Infotainment*: Giving infotainment (news messages, weather forecasts, small games, short films, etc.) to the train passengers, either through fixed screens and/or through a portal, a more agreeable service could be offered. This only requires a relative small bandwidth with no delay or real-time connection constraints for updates; large updates

can be made when cheap network connections are available (e.g. in stations or during the night).

- *Internet service for the passengers:* This service would be an addition to the infotainment system where passengers can't freely make use of the Internet. In order to stimulate the modal switch between passengers from second to first class, a free Internet service is offered to first class travellers (available today by SJ and Thalys). Important to note is the bandwidth that could be offered to the passenger: is it best effort (shared amongst all users) or is there a guaranteed bandwidth per user?
- *Advertising:* This could be offered in addition to the infotainment service, in order to present a viable business case. A large (focused) audience can be reached, even targeted towards geographical areas e.g. advertisements for a city when the train reaches its destination.
- *Seat reservation:* This service is interesting for long-distance trains, certainly when this information would be available for the train crew.

Situating the services along the train's trajectory

The moment services will exchange data between the train and the wayside is very important to determine the correct technological solutions. Figure 3 shows the mapping of the services along a train's daily trajectory. An indication is given about the number of data transmissions and the direction of the data transfer (>W: to the wayside; >T: to the train; T<>W: both ways).

- *Depot:* At night large data can be offloaded (e.g. CCTV videos) or uploaded (advertising, entertainment) as this is an off-peak period in which the networks are less used and moreover the train is not moving at this moment. In the morning a remote train preparation service could be activated which can update trains or indicate potential problems.
- *Departure station:* information about the daily trajectory can be uploaded, possibly also seat reservations (to be updated along the trajectory).
- *Any position along the trajectory:* critical diagnostics, GPS coordinates, crew communication and CCTV are amongst the services that always need to be available. Other services such as Internet for the passengers or news flashes can be interrupted for short periods (no full coverage required).
- *Intermediate stations:* updates for seat reservation or upload/offload of information when high capacity networks are available.
- *Crossings:* advanced hazard warning systems can be activated at a predefined distance before/after railway crossings in order to detect potential problems in advance.

Techno-economic evaluation of Internet services on-board trains
 VAN OOTEGHEM, Jan; NAUDTS, Bram; LANNOO, Bart; VERBRUGGE, Sofie;
 COLLE, Didier; PICKAVET, Mario

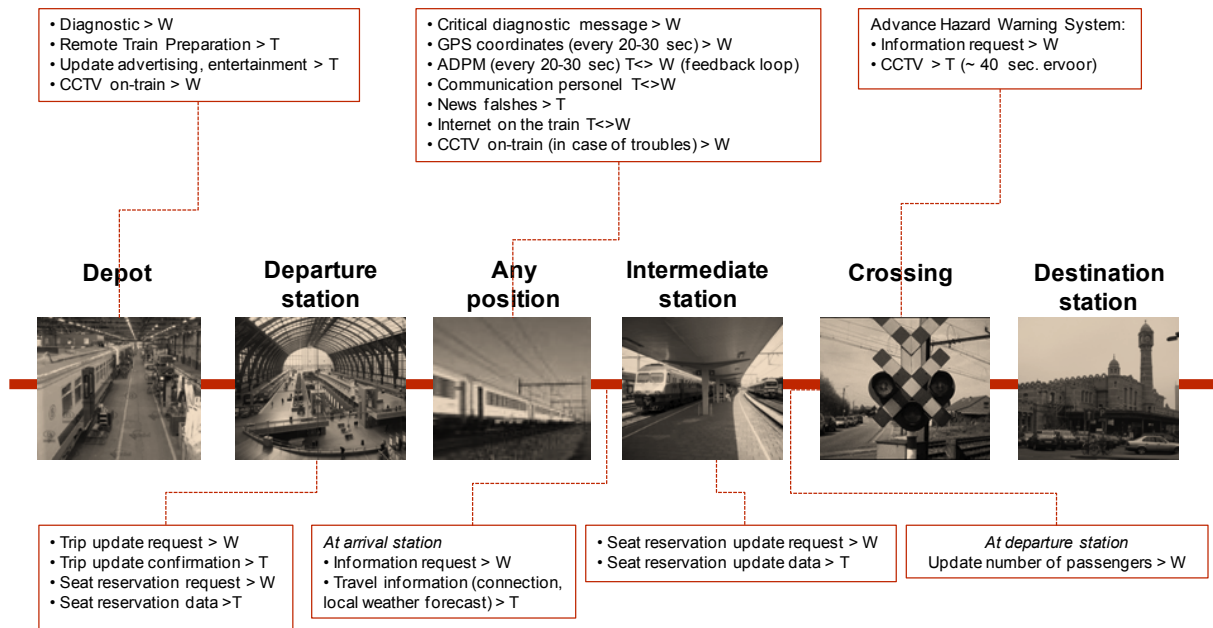


Figure 3: Situating the services along the train's daily trajectory

Next to the moment of sending information, it will also need to be possible to transfer the data to/from the train from/to the wayside. A priority list must be set up either for the services (in order to separate the critical data from the non-critical data) and the networks (depending on the technical characteristics of the networks e.g. delay, bandwidth, reliability, etc.) to be used.

Service specifications

In Table 3 an overview of the required bandwidth per service is given. The figures are gathered from different sources: from the iMinds TR@INS and TRACK projects [14], ESA ARTES 1 study [17] and documentation from Bombardier Transportation [14] and Nomad Digital [1].

The GPS coordinates and the critical diagnostics data are automatically sent to the wayside every 20 to 30 seconds. Passenger counting data is sent to the wayside when leaving the railway station. The images of the on-board CCTV are on request of the train crew or the control centre. The offered bandwidth for communication and ADPM/DAS is symmetric to guarantee the communication between wayside and the train crew. For the services seat reservation, AHWS, infotainment and travel information, a request is sent to the wayside to send the appropriate data from the wayside to the train. The required bandwidths of CCTV on-board and AHWS are highly dependent on the used resolution of the images and the number of frames per second.

Bandwidth for passenger Internet services includes basic web applications as well as streaming. As the requested bandwidth is not constant and is multiplexed over several simultaneous users over time, we consider a lower (guaranteed) down- and uplink in order to cope with this bandwidth consumption. Infotainment and advertising need a periodic content update, which can be done at night in the depot. Of course, newsflashes, weather forecasts and other real-time messages are refreshed during the day.

The required bandwidth per service in combination with the location of the service is used in the model to estimate the bandwidth demand along the trajectory.

Table 3: Required bandwidth per service

Category	Service	Bandwidth downlink (>T) [Mbps]	Bandwidth uplink (>W) [Mbps]
1	GPS coordinates	0	0,001
	Critical diagnostics	0	0,001
	Remote Train Preparation	0,005	0,005
	Communication	0,009	0,009
2	ADPM / DAS	0,005	0,005
	Passenger Counting	0	0,001
	CCTV on-board	0	2
	AHWS	2	0,001
3	Infotainment (content update)	0,05	0
	Infotainment (e.g. newsflash)	0,005	0,001
	Travel information	0,005	0,001
	Advertising	0,05	0
	Seat reservation	0,001	0,001
	Internet browsing, email, streaming	0,1 (per pass.)	0,025 (per pass.)

COST/BENEFIT MODEL

Costs

The capital expenses (CapEx) comprise all investment costs that can be depreciated over time. In our model CapEx has been split into two parts: costs for upgrading trains with the required network equipment and costs related to the rollout of new dedicated telecommunication networks for the train to wayside communication. The CapEx for installing the network equipment inside the train is split up for cab- and slave carriages. The cab car contains the outdoor antenna as well as the rack with network connection modems for monitoring and coordinating the on-board and train-to-wayside network connection. Slave carriages are only equipped with a (mostly) fixed backbone network and Wi-Fi antennas.

A cost difference can be observed between the different technologies used for the outdoor link. Network related CapEx contain costs for rolling out a dedicated Wi-Fi and/or WiMAX network, including acquiring ground for sites, poles, antennas and sectors, backhaul links and core equipment. We assume that a certain amount (fixed at 75% for WiMAX, 25% for Wi-Fi) of the poles along the tracks can be reused. Besides a network operating center (NOC) with dedicated backbone network connection needs to be foreseen on the wayside for monitoring all trains, manage the data sent from and to the train, and distribute it to the appropriate actors. The operational costs (OpEx) contain the yearly recurring costs. Sales, billing, marketing and helpdesk are required for offering the service independent of the proposed technology. Maintenance and repair for train equipment is a percentage of the total train CapEx cost. Network planning, monitoring, repair and maintenance, and leasing costs are more specific for each scenario, depending on the combination of technologies. A critical OpEx cost is bandwidth consumption, certainly for mobile and satellite network usage (very expensive).

Revenues

Depending on the type of service, the related revenues or cost savings are calculated. For passenger services this is a fixed amount of revenue per user per day taken into account a depreciation when the service could not be offered (e.g. due to lack of bandwidth capacity). Vital control data services and crew services offer cost reductions (e.g. energy cost saving due to eco-optimized driving, less maintenance or carriages ordered when trains are monitored, less cleaning and repair due to decreased vandalism when CCTV cameras are places).

MULTI-ACTOR ANALYSIS

The integrator, the consortium and the train constructing model are three examples of currently existing interaction models [17]. In the integrator model, the INT has the lead of the project. The integrator acts as a boundary between the train operating company and the other parties to offer the service. In the consortium model, multiple actors form a consortium to establish the project. Each party in the consortium has a well defined role and responsibility. In the train constructing model the train constructing company offers network services as an option to persuade potential customers into buying its new locomotives and railway carriage or as a mean to receive valuable information and increase its own operational efficiency.

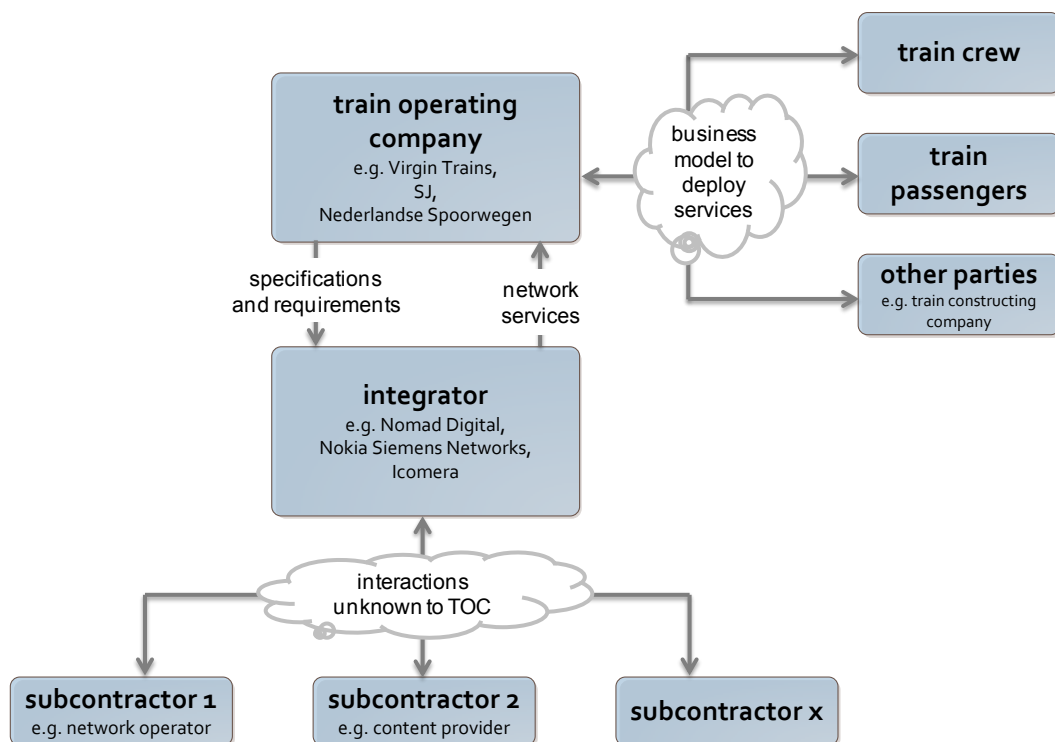


Figure 4: Integrator business model for offering Internet services onboard trains

We focus in this paper on the integrator model (Figure 4) where one party takes the lead and provides an integrated solution. This model is often used when the TOC wants to add new services that require wireless technology while the current rolling stock does not have the necessary infrastructure installed. The integrator is responsible for the complete deployment process from design over installation to network management and maintenance. The TOC

awards, based on a set of criteria, a contract to the integrator who then deploys the required services during the time frame stipulated in the contract.

CASE

To show the possibilities of this model we have made a case for the Belgian railway network. Input and benchmark has been based upon previous work [4][19][20]. All InterCity (IC) and InterRegional (IR) lines are taken into account rolled out over a period of 5 years. Figure 5 gives an indication of the lines taken into account, showing the densest trajectories in terms of passenger traffic in a thicker line. The final figures used in this model are arbitrary.

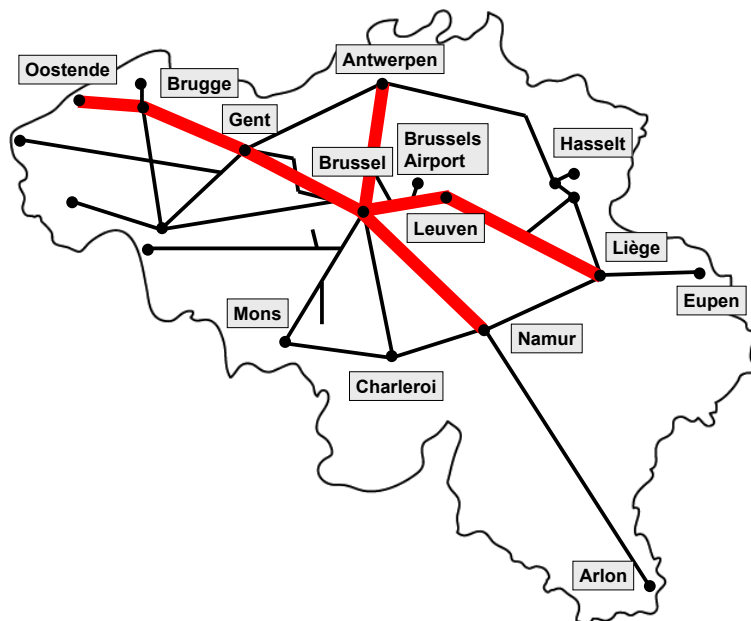


Figure 5: Mapping of the IC and IR lines for the Belgian railway network.

We have defined 3 scenarios. First we only consider a passenger Internet service, offered via the available mobile networks. In a second scenario, we considered additional (non-)passenger related services (such as diagnostics, AHWS, CCTV, crew communication, advertisement). In a final scenario we will indicate the benefits of investing in a dedicated telecommunications network in order to reduce the overall mobile bandwidth costs by combining mobile (HSPA, UMTS and GPRS) networks with WiFi available in all stations. The current availability of the technologies over the full trajectory and the special locations (stations, cross roads, cleaning rooms, working places) is shown in Table 2.

Scenario A: Passenger Internet service

In this first scenario, we only consider passenger Internet service, offered via the available mobile networks, as has been implemented in several real life cases. Figure 6 indicates the total cost breakdown over a 10 year period for this scenario. Most of the costs are operational (OpEx); capital expenses (CapEx) only account for a small fraction of the total costs. The CapEx contain equipping the trains (93%) and network related costs (7%), which is logical as we make use of existing telecommunication network infrastructure and refurbishing trains requires a large investment. Considering the OpEx, mainly the very expensive mobile

bandwidth consumption drives the network cost, and the overall total cost of ownership over a 10 year period, as can be seen in the top left figure.

As can be seen in Figure 7 the different mobile technologies are not capable of offering enough bandwidth for the public Internet service. In stations the coverage of networks is nearly perfect, thanks to the availability of HSPA. Along the trajectory on the other hand, the decrease of available bandwidth can be explained by the introduction of equipped trains until 2015, and an overall uptake of the service' adoption over the years.

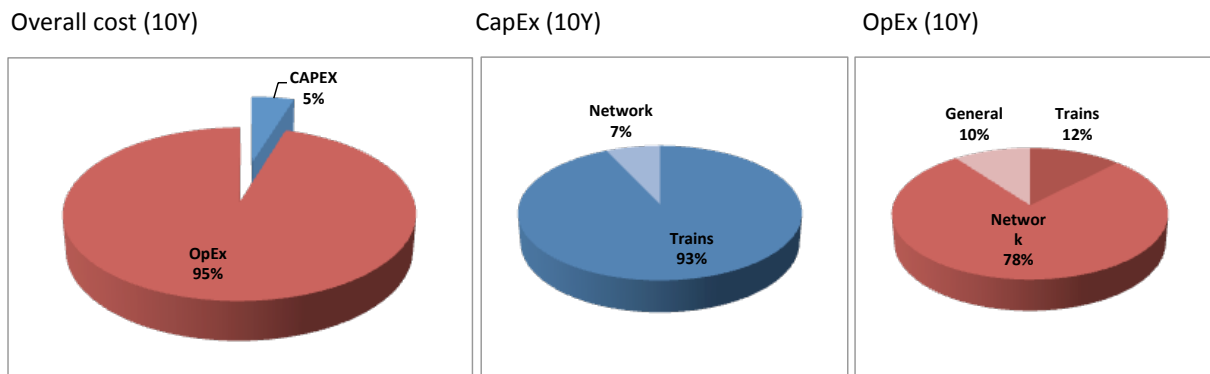


Figure 6: Cost distribution for scenario A

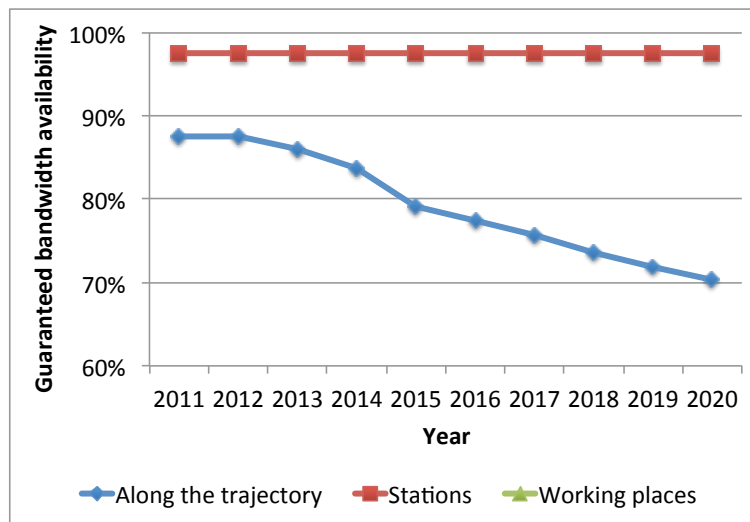


Figure 7: Bandwidth availability for offering the service per location

Many actors are involved with the deployment of Internet services on-board of trains and each requires a positive business case in order to further participate. As mentioned before we consider the integrator business model. The NPV for the different actors can be seen in Figure 8. The train operating company (TOC), service provider (SP) and integrator (INT) bear all the costs, and thus the risks. Only the SP's business case is sustainable, while the others are unprofitable. Only the network provider is certain of its large revenue flow, thanks to the enormous (expensive) mobile network usage costs. As the overall business case for the TOC, INT and SP is losing money, this model is not sustainable. The cost and revenue allocation scheme for all actors is shown in Table 4.

Table 4: Cost and benefits allocation scheme for all actors

Allocation scheme	TOC	CP	SP	INT	NOP	TMC	TCC
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Train related costs	65%	0%	20%	15%	0%	0%	0%
Network related costs	0%	0%	70%	30%	0%	0%	0%
Benefits	0%	0%	70%	30%	0%	0%	0%

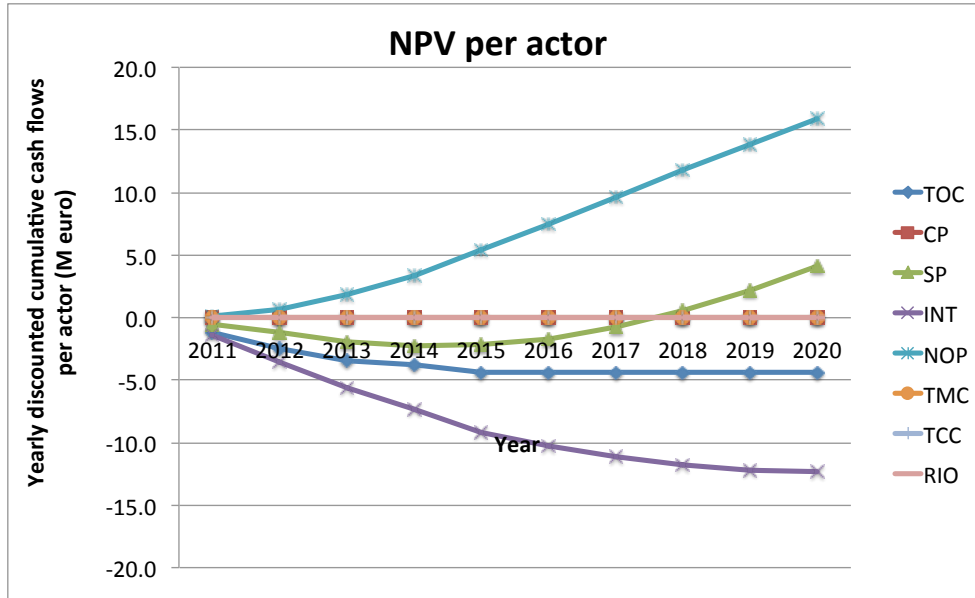


Figure 8: NPV multi-actor analysis results for scenario A

Scenario B: multiple services

As could be concluded from the previous scenario the business case was not sustainable. Adding additional services making use of the available onboard network infrastructure could improve the viability of the case. Adding new services also implies the introduction of new actors such as the train constructing (TCC) and maintenance (TMC) company. We only consider available mobile networks in this case. The bandwidth availability over the years can be seen in Figure 9 and shows the same pattern as in Figure 7. In this case the working places are also included as these are used for train remote preparation and offload/upload data.

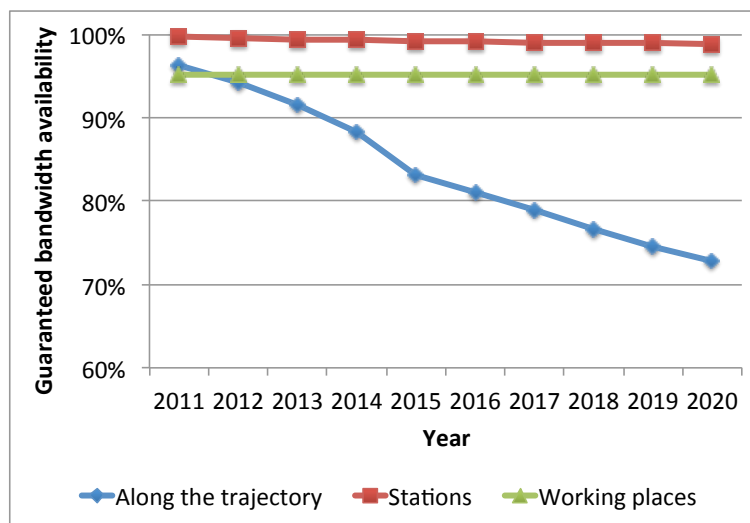


Figure 9: Bandwidth availability for offering services per location

Multiple actors are now involved in the scenario, each with their own business case. The additional network costs for the rollout of the Wi-Fi network in stations has been allocated to the actors making use of the network, as can be seen in Table 5. The integrator and service provider, which depend most upon the passenger related services (also the most bandwidth consuming services, as can be seen in Figure 11) suffer in the first years with loss. For the other actors the benefits (or cost savings) from the additional services are compensating those costs: automated driver performance monitoring, train diagnostics, GPS location, remote train preparation and CCTV for the train operating company; train diagnostics for the train manufacturing and maintenance company. The content provider (entertainment and streaming services) and railway infrastructure owner (advanced hazard warning system) are not considered in this scenario. The network provider again benefits from network bandwidth usage. As his benefits in the previous scenario were excessive compared to the other actors, we now consider that they take some of the costs for their account. We can now see that the business case for each actor can be profitable.

Table 5: Cost and benefits allocation scheme between all actors

Allocation scheme	TOC	CP	SP	INT	NOP	TMC	TCC
Train related costs	65%	0%	10%	15%	0%	5%	5%
Network related costs	13%	0%	62%	13%	8%	2%	2%
Benefits	15%	0%	56%	24%	0%	2%	2%

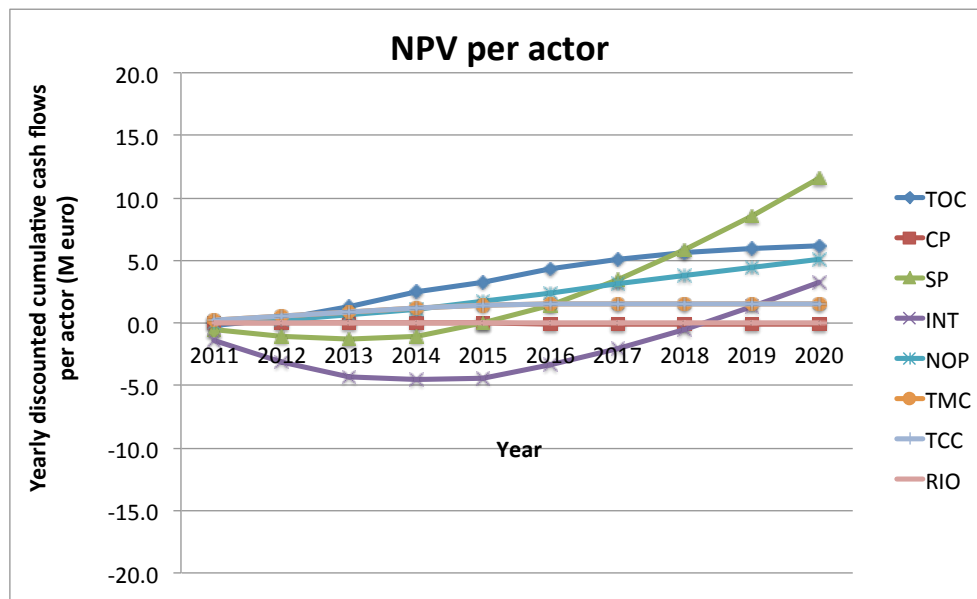


Figure 10: NPV multi-actor analysis results for scenario B

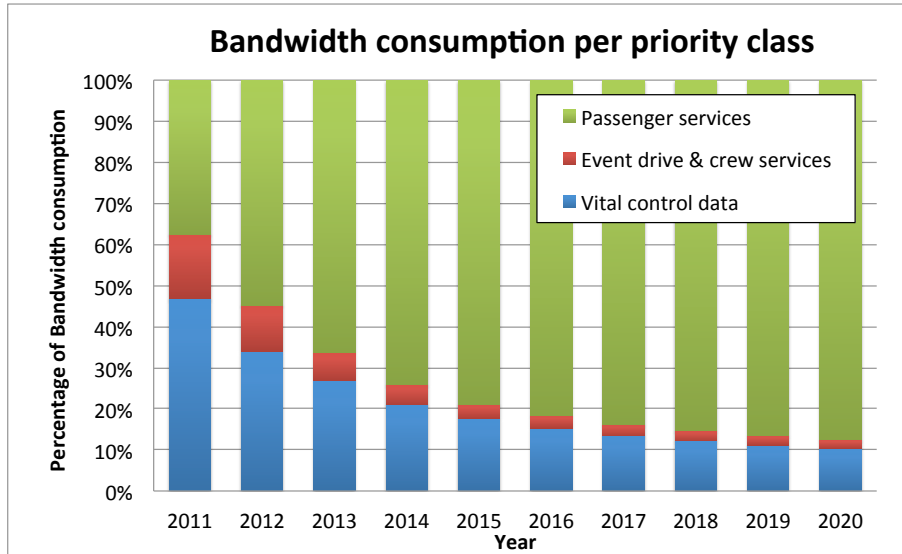


Figure 11: Bandwidth consumption per priority class

Scenario C: dedicated telecommunication network

This scenario builds furthermore upon the previous, considering multiple services, but now we also introduce the use of existing and installation of additional Wi-Fi base stations, in all train stations (Figure 12). The CapEx network costs have increased due to this network rollout, but still comprise only a small amount of the total cost of ownership over 10 years. A lot of costs related to the rollout of the Wi-Fi network are also incorporated in the network OpEx (planning, operations, maintenance, backhauling, site leasing, etc.).

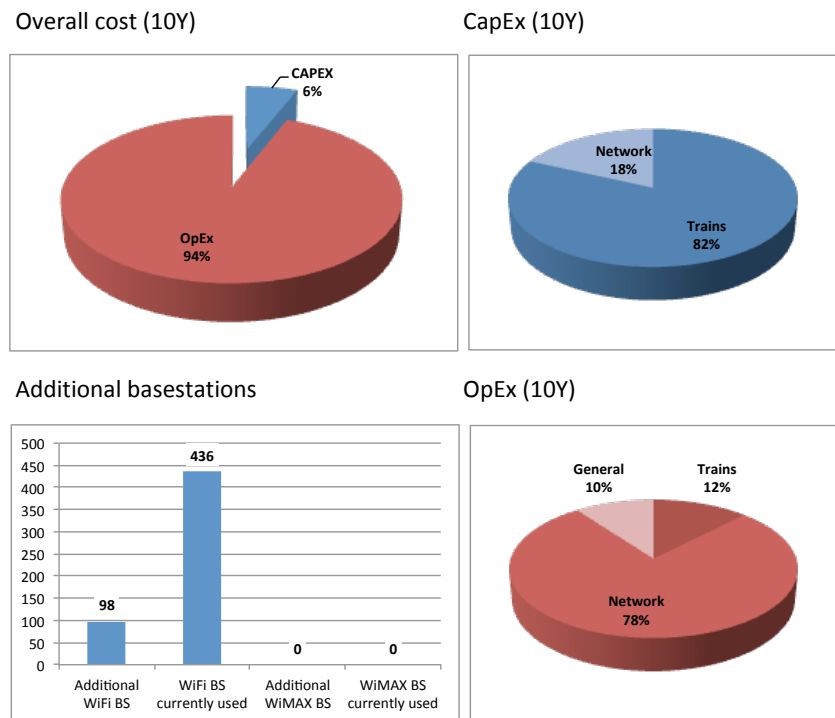


Figure 12: Cost distribution for scenario C

Figure 13 shows the NPV multi-actor analysis for scenario C. The business cases for most actors involved have been improved due to the installation of the dedicated Wi-Fi network in all stations (trade-off between investment cost and cost savings due to less mobile network usage). Especially the service provider benefits, as his services consume most bandwidth. As the investment is relative low for Wi-Fi in stations, and will be more expensive when rolling them out along the tracks (higher costs for backbone connection, dedicated poles for the antennas, etc.) a constant trade-off must be made whether the incremental investment is still profitable.

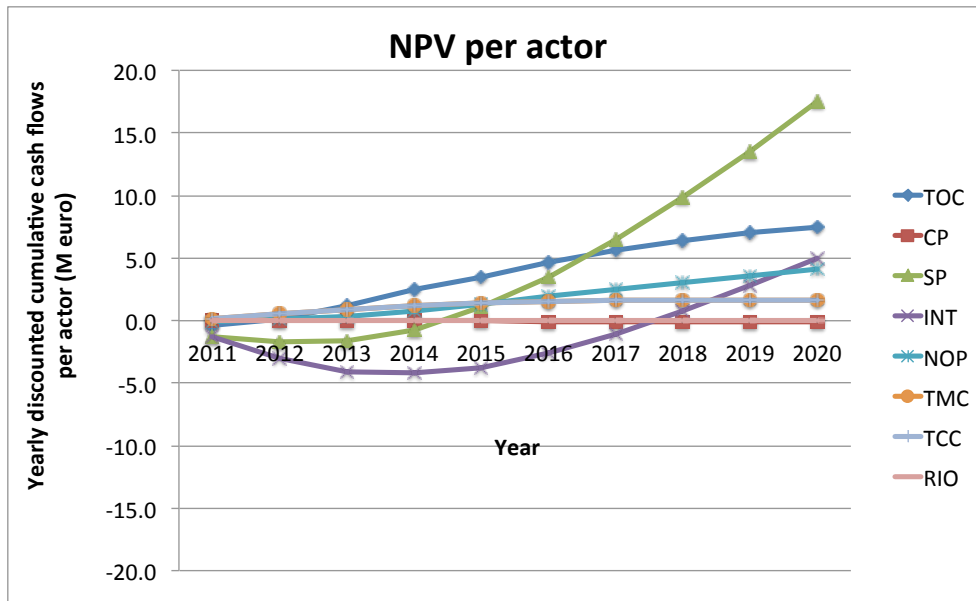


Figure 13: NPV multi-actor analysis results for scenario C

When taking a look at the overall consumed bandwidth per technology (Figure 14), about 12% of all network usage was over the dedicated Wi-Fi network (although only rolled out in the stations). As mentioned before, this was a profitable investment, as the savings in mobile network capacity was larger than the network costs for installing Wi-Fi.

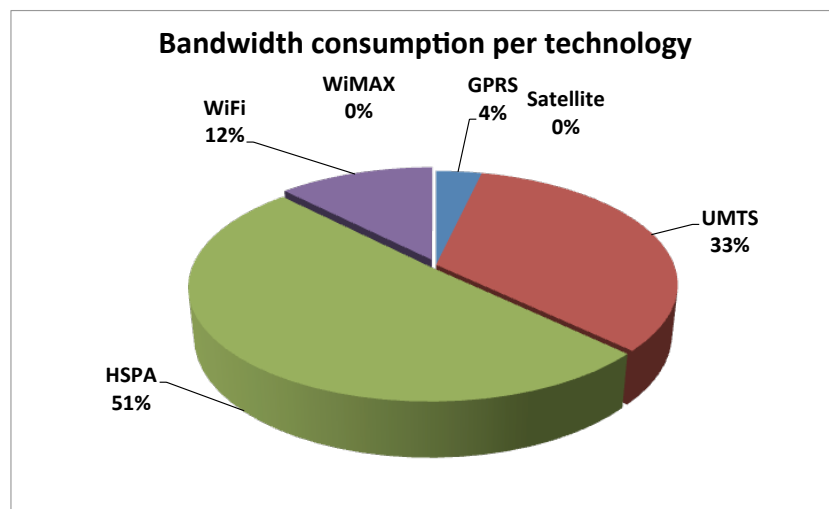


Figure 14: Bandwidth consumption per technology

CONCLUSIONS AND FUTURE RESEARCH

On-board Internet services such as passenger Internet should prove to be a revenue source for operators however often a positive business case cannot be realized due to a high total cost. The introduction of new services that run over the same communication network will determine the future success of on-board Internet services.

Within this paper we have described what to consider when evaluating the viability of Internet services onboard trains. An Excel based tool has been developed, taking into account technical (railway infrastructure, service requirements such as bandwidth, availability of technologies for train-to-wayside communication), economic (costs and revenues) and business parameters (actors involved, business models, multi-actor allocation schemes) in order to quantitatively evaluate the economic viability of Internet services on-board trains.

We described the different network technologies that could be used to offer train-to-wayside connection. A split up is made between mobile networks currently available such as GPRS, UMTS or HSPA, dedicated wireless networks such as Wi-Fi or WiMAX and satellite networks. Each of these technologies have their advantages as well as their drawbacks. Most of the time a trade-off must be made between large investments and low operational costs (e.g. for Wi-Fi networks) versus small investments and large operational costs for (e.g. bandwidth capacity rental for mobile or satellite networks).

Important to consider is the business potential for each innovative service, either for passengers (basic Internet services, entertainment and infotainment), crew (communication, CCTV) and machine-to-machine services (vital control data, remote train preparation, etc.). Next we have described the different actors involved in the value network and service offering ranging from train owner, operating, maintenance and constructing company over integrators, service and content providers to passengers, crew and on-board equipment. We have opted for the integrator model within this paper.

A cost-benefit model has been worked out, taking into account the proposed business model (with appropriate cost and benefit allocation scheme for the different actors involved) in order to present the business case for each actor involved in the offering of Internet services onboard trains. A case study for Belgium has been presented showing that the introduction of additional services next to a passenger Internet service makes the business case profitable for all actors. When considering the rollout of dedicated network infrastructure, a trade off must be made between the investment and the cost of keeping the network up and running versus the cost savings from the use of mobile network bandwidth. On the other hand as mobile networks do not cover all the tracks, these dedicated networks could be used as gap fillers in order to obtain a full network coverage for your services.

Future work comprises of the introduction of GIS based network information such as the automatically obtaining real life railway network infrastructure (locations of tracks, stations, cross roads, etc.) and the availability of telecommunication networks and related bandwidth.

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