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11/2015

November | € 22 | C 11180

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Cost efficiency analysis of the satellite based train control system 3InSat in Germany

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DB Netz AG is aiming at cost effective alternatives to conventional train control systems on low density lines. For this purpose, the cost efficiency of the 3InSat system – a satellite-based platform for train protection – is analysed by comparing the net present value of equipment cost for 3InSat with the alternative systems ERTMS-Regional, ETCS Level 2 without lineside signals and conventional signalling. From the results it can be told that 3InSat offers a cost saving potential, mainly due to the fact that physical Eurobalises can be replaced by virtual balises.

1 Introduction and motivation

Germany's national infrastructure manager DB Netz AG operates about 33 300 kilometres of the German rail network, 12 000 kilometres of which are characterised as low traffic density lines. Most of these lines belong to the regional network. A crucial aspect of cost efficiency is the train control and management system. Currently, most of these lines feature a system with relatively high capital and operational expenditures in relation to their number of trains. In order to improve the cost efficiency of these lines, DB Netz AG scouted for innovative alternative systems, amongst them 3InSat and ERTMS-Regional [1]. The aim of the following analysis is to assess the cost efficiency of one of the most promising ones, which is the 3InSat – Train Integrated Safety Satellite System [2]. 3InSat offers satellite-based train positioning and enables the replacement of fixed Eurobalises by virtual balises. In doing so, it is supposed to meet the Safety Integrity Level 4 (SIL4) safety requirements and to be compatible with the ERTMS standard. Furthermore, the system provides functionalities for satellite-based telecommunication between train and infrastructure.

In the 3InSat project, this system is to be developed, tested and validated in a real set-up. Led by Ansaldo STS and cofunded by the European Space Agency, several international project partners are involved, including DB Netz AG and the German Aerospace Center (DLR). The project's work plan comprises several work packages regarding national scenarios of a number of countries. Besides the economic assessment, the German scenario includes a comparison of the system's functionalities with the operational procedures and requirements of the German rail system. From this, further requirements for the 3InSat system are derived. The analysis of the cost efficiency, the so-called Business Case German Scenario, is presented in this article. It is carried out by the DLR in close cooperation with DB Netz AG. The aim is to deliver a basis for a decision about whether or not DB Netz AG should continue their participation in the pursuit of this satellite-based technology. That is why the analysis is strictly bound to the framework, conditions and boundaries of the German railway network. Since the cost efficiency analysis is worked out in parallel to many other activities at a relatively early stage of the project and before the completion of a prototype, not all information about the 3InSat system architecture and functions are available in detail, so a number of assumptions have to be made.

2 Method and approach

2.1 Scenarios

In order to evaluate the cost efficiency of 3InSat, the life cycle costs of this system are compared to alternative technologies. Thus, the cost saving potential of the 3InSat system due to the reduction of fixed Eurobalises will become apparent.

For the low density lines in focus, there are three alternative signalling systems to be considered:

- ETCS Level 2 without lineside colourlight signals (since a variant without conventional lineside signals provides the highest comparability with the other systems that have no sophisticated fall-back technology),
- ERTMS-Regional, (a cost-reduced variant of ETCS Level 3 for regional lines without conventional lineside signals and without track-side train detection) and
- Germany's common conventional signalling system (the so-called Ks-System).

The current track equipment does not affect this analysis since all scenarios are assumed to have equal dismantling costs. A re-use of any part of the preceding track equipment, as well as any questions of migration are also excluded from the scenario definition.

In contrast to the application of 3InSat in other countries, in the German scenario the telecommunication components of 3InSat are not considered. This is because it is still unclear if voice radio will be realised in 3InSat. This functionality is however mandatory in the German rail network for passenger transport. On the other hand, there is a dense voice radio GSM-R network available in Germany on most of the considered lines. Yet, an upgrade is necessary in order to meet the European EIRENE requirements to provide ETCS data communication between trackside infrastructure (Radio Block Centre (RBC)) and trains.

The line characteristics are derived from generic line standards according to DB Netz AG regulations [3]. DB Netz AG's network of regional lines consists of three standards, called R120, R80 and G50, the characteristics of which are summarised in Tabel 1.

The most significant differences between them are the number of tracks, the number of stations and the block lengths.

Since R120 and R80 are described by an upper and lower limit, the arithmetic mean of every attribute constitutes an additional "mean scenario" for R120 and R80. Altogether, this leads to a number of seven generic lines. The total length of the network considered for the application of 3InSat in Germany adds up to around 10 000 kilometres of regional lines (as shown in Table 1) plus an additional 2 000 line kilometres of the G50 standard within the core network. The generic lines have a standardised length of 100 and 50 kilometres respectively. By means of the parameter "line length (regional network)" the cost analysis can however be extended to any network in focus.

The number of trains to be equipped is assumed to be seven for R120, five for R80 and three for G50. Due to the fact that they are presumed to vary in practice, these figures are subject to a sensitivity analysis.

All in all the cost efficiency of the 3InSat system will be analysed on the basis of a cost comparison between four equipment alternatives for seven reference lines to allow for conclusions about the systems' suitability for different line characteristics.

		R120		R80		G50
		upper limit	lower limit	upper limit	lower limit	
line length (generic)	[km]	100	100	100	100	50
track length	[km]	180	120	100	100	50
number of tracks	[-]	1-2	1-2	1	1	1
number of stations	[-]	4	4	9	5	3
mean distance between stations	[km]	20	20	10	17	17
block length	[km]	5	10	no blocks --> station distance		
line speed	[km/h]	81-120	81-120	51-100	51-100	< 50
number of trains per day and direction	[-]	50	25	30	18	5
regional trains per day and direction	[-]	40	20	25	13	0
freight trains per day and direction	[-]	10	5	5	5	5
line length (regional network)	[km]	4971		4639		287

Table 1: Characteristics of generic lines [source: authors]

2.2 Assumptions for alternative systems

In this analysis, costs are not contrasted to any benefits. This is due to the fact that the benefits of the compared systems are considered equally high, as no significant differences in track capacity, revenues, safety or external effects were identified. Table 2 shows a comparison of the elements that determine the systems' costs.

The most significant feature of 3InSat in terms of cost reduction is the fact that no fixed Eurobalises are needed. In return 3InSat requires a special train equipment in addition to the ETCS onboard equipment. This includes GNSS-Receivers and antennas, a location determination system (LDS) as well as a track database in the form of a digital map that provides the position of each Eurobalise and its contained information. The allocation of the digital map as an element of the train equipment is based on an assumption, since no detailed information about its architecture is available at present. It is also possible that it may become a centralised element of the infrastructure. Also, in terms of the infrastructure, additions have to be made in the form of the so-called TAL-server that provides the train with high-precision positioning data from the European Geostationary Navigation Overlay Service (EGNOS) and reference stations which are subsumed under the 3InSat EGNOS-service cost element. There is no detailed information available at the moment whether this service will be charged. In the aviation sector, it is a free service, so it is reasonable to assume the same for the rail sector. However, the possibility of a charge cannot be absolutely excluded.

	ETCS Level 3		ETCS Level 2	
system elements	**3InSat**	**ERTMS-R**	**ETCS L2oS**	**Ks-System**
Infrastructure				
electronic IXL with OFC	x	x	x	x
lineside colour-light signals	–	–	–	x
lineside axle counters	–	–	x	x
intermittent ATP (PZB)	–	–	–	x
ETCS RBC	x	x	x	–
ETCS Eurobalises (fixed)	–	x	x	–
GSM-R upgrade for ETCS L2/L3	x	x	x	–
3InSat EGNOS-service	x	–	–	–
3InSat TAL-Server	x	–	–	–
Train				
PZB on-board equipment	–	–	–	x
ETCS on-board equipment	x	x	x	–
3InSat on-board equipment	x	–	–	–

Table 2: System elements of equipment alternatives [source: authors], OFC = Optical Fiber Cable; IXL = Interlocking; ATP = Automatic Train Protection; PZB = "Punktförmige Zugbeeinflussung"; TALS = Tracking Area LDS Server

All other cost components are the same as for ERTMS-Regional and ETCS Level 2, including the interlocking. For each system, the cost of the interlocking is derived from the sum of its signalling equivalent units (SEU). A SEU represents outdoor and indoor installations of a field element as well as its share of the operations control and maintenance centre, and includes the cost of all project phases from conception to implementation. Each field element has a specific factor of SEU that it resembles. By allocating a cost factor to one SEU, the cost of the whole interlocking can be calculated by summing up the SEUs of its field elements. In the case of ERTMS-Regional for example, where the axle counters have to be subtracted, the mere cost of the hardware, i. e. the physical field element and central axle counting equipment itself are discounted, since the logic behind the clear track detection and its processing within the interlocking is required for ETCS Level 3 applications, too.

The actual number of fixed Eurobalises has an important influence on the cost reduction of 3InSat and results from the following assumptions: Every home signal as well as every starter signal requires on average three fixed Eurobalises. Level crossings with automatic train protection hold on average three Eurobalises for each track and direction. Since in the regional network the density of level crossings is high enough, there is no need to take the re-positioning Eurobalises every 1.8 kilometres into account. For the same reason, the Eurobalises for block signals are not considered. The number of Eurobalises was calculated individually for each scenario. At an average, there are 1.9 Eurobalises per kilometre of single track. Besides that, the operational costs are decisive for the profitability of 3InSat, i.e. the costs for maintenance and replacement of fixed Eurobalises. There are only few experiences from the operation of Eurobalises in the German network, so their operational expenditures have to be estimated. From the DLR's and DB Netz AG's point of view it is reasonable to assume operational Eurobalise costs in the magnitude of about 1 % of the capital expenditure. This value resembles roughly the ratio of operational to capital expenditures of other field elements. To cover this assumption, a ten times higher value is tested in the sensitivity analysis.

The benefit of ERTMS-Regional and 3InSat in comparison to ETCS Level 2 lies in cutting out lineside axle counters. Despite the fact that a substitutional technical solution for train integrity control in both cases is not defined yet, no further cost for this functionality is assumed here. Finally, the conventional Ks-System does not contain any ETCS-component but lineside signals and intermittent ATP equipment (the so called PZB) at trackside and on board.

It is assumed that there is no difference in operation costs between the alternatives. Equally, in case of failure, operational rules provide the fall-back solution for every system.

3 Calculation of life cycle cost

It is assumed that each system will be operated for 40 years after a span of five years installation time. Dismantling costs are not considered. The cost comparison of the alternatives will be based on the net present value. This view includes the expenses for the railway undertaking as well as for the infrastructure manager. To allow for a straightforward allocation of expenditures between these two actors, the costs for trackside and train equipment are disclosed separately. External costs like emissions or effects from modal shift are not taken into account, since neither a usable line capacity increase nor a traffic increase is expected from a change of infrastructure equipment on regional lines.

The initial capital expenditures are distributed in a DB-specific ratio over the five years of the start-up phase. During the following operation phase, the capital expenditures as well as the operational expenditures of each system are determined for every year of the life cycle. The reinvestment costs are considered in the respective years according to the individual life span of the components. In order to calculate the net present value of the life cycle cost, a DB-specific interest rate is applied. The capital expenditures include the hardware and all related project planning and implementation costs. Operational expenditures consist mainly of maintenance costs and service charges. Energy costs are not considered due to their minor share of the overall costs, and personnel costs are excluded because they are assumed to be equally high in each technology. To account for rising prices, the costs for capital and operational expenditures are subject to a nominal increase per year.

Finally, the most influential parameters as well as parameters with high uncertainties regarding their value are undergoing a sensitivity analysis, in order to find out how the results of the cost comparison vary depending on those single cost factors.

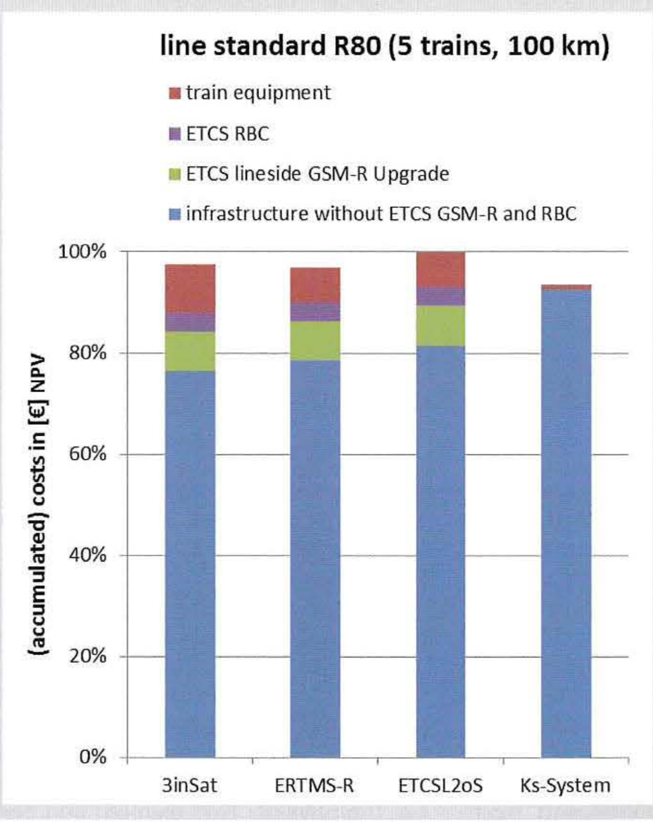

Figure 1: Accumulated costs of the alternatives (source: authors)

4 Results and outlook

The scenarios on all R80 and R120 lines show basically the same ranking of the four compared technologies. The R80 mean scenario gives a representative impression of the overall outcome (figure 1).

The life cycle costs only differ slightly between the four technologies. The highest cost share is allocated to the infrastructure, with the interlocking as the most influential cost component. As expected, 3InSat has the lowest costs in infrastructure but highest in train equipment. The reason why the conventional signalling system has the lowest overall costs seems to be the investment for the GSM-R-upgrade for ETCS. Since these costs, as well as those for ETCS train equipment, appear relatively high in relation to the sum of life cycle costs, further observation is required:

As part of a sensitivity analysis, a scenario is set up in which lower ETCS train equipment costs are reached and the costs for lineside GSM-R upgrade for the ETCS variants are negligible. This assumption is reasonable, since there will be future research in order to develop alternative communication technologies that will exceed GSM-R in terms of cost-efficiency. Lower ETCS costs might be achieved through the European research project openETCS. This project aims at a cost efficient and reliable implementation of ETCS train equipment. Especially the development process of the on-board ETCS software should be optimised by using open standards [4][5]. The results are shown in figure 2. In this case, 3InSat and ERTMS-Regional become financially much more attractive and the conventional signalling system is the least favourable one.

Furthermore there are a number of other uncertainties regarding decisive input data. The economic efficiency of 3InSat mainly depends on the quantity and cost of Eurobalises, the number of trains to be equipped and the cost for special 3InSat infrastructure and train equipment. Whereas 3InSat specific infrastructure cost is presumably negligible, the cost for train equipment like the track database will be a significant cost driver and difficult to estimate at this stage. With these parameters, a pessimistic and optimistic scenario from the 3InSat point of view is set up. For the figures in question, oppositional assumptions are made. Pessi-

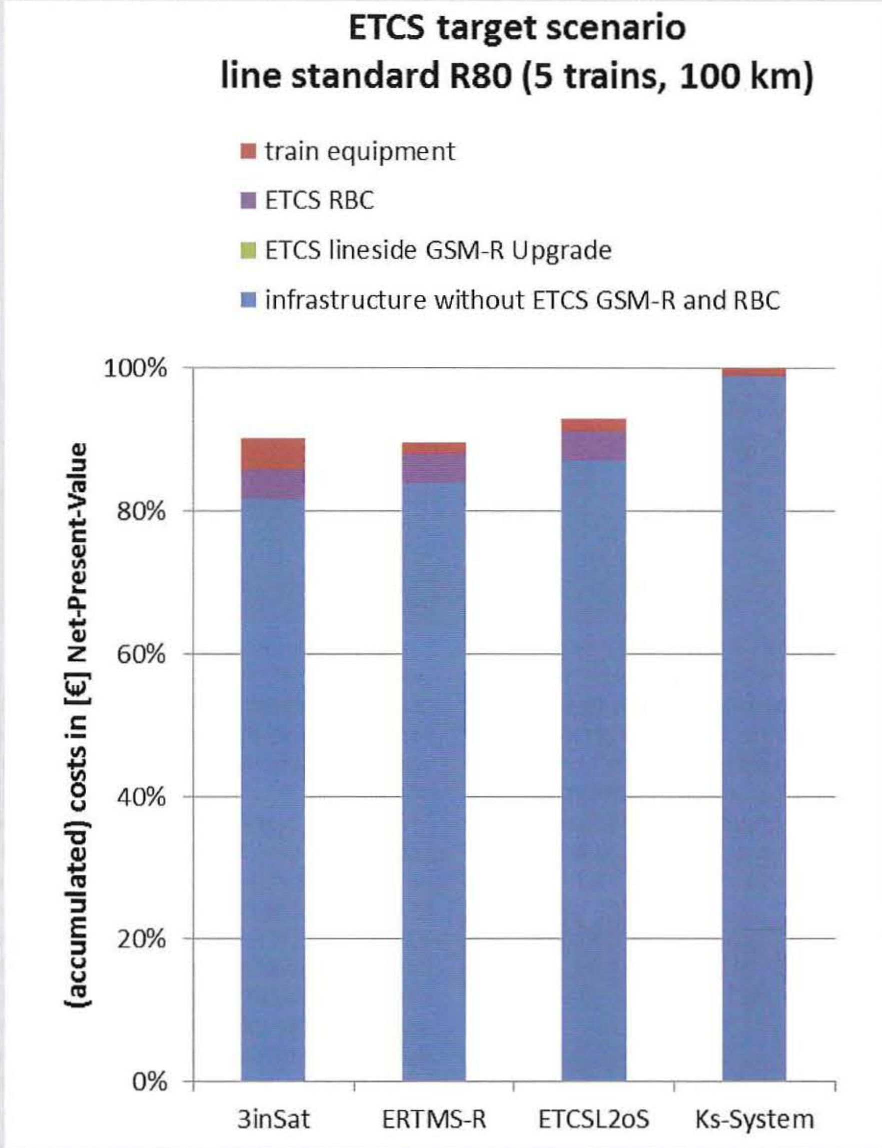

Figure 2: Accumulated costs in the ETCS target scenario *(source: authors)*

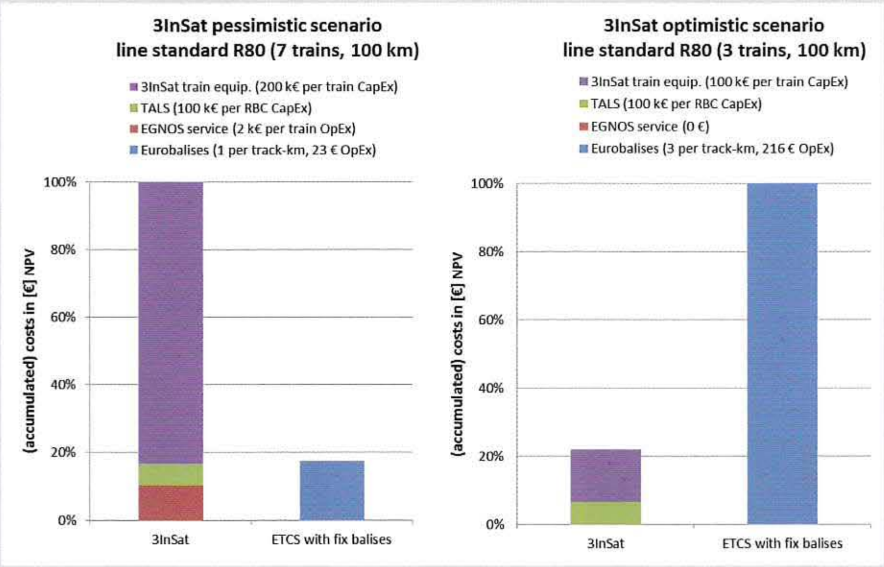

Figure 3: 3InSat optimistic and pessimistic scenario (accumulated costs) (source: authors)

mistic assumptions are: a high number of trains to be equipped accompanied by high 3InSat equipment costs and a small number of Eurobalises to be replaced by virtual balises. The Eurobalises' operational expenditure is assumed to be low. Additionally, a fee for the EGNOS service is assumed. The optimistic scenario is constituted by opposed assumptions.

Figure 3 contrasts the pessimistic and optimistic view on the sum of cost elements that differ between 3InSat and ETCS with fixed balises (ERTMS-R and ETCS L2oS). The effect of the different scenarios is substantial: In the pessimistic scenario the 3InSat system is not economically efficient whereas in the opposite case it is distinctly efficient, compared to a conventional ETCS alternative.

5 Conclusion

As a conclusion, it can be stated that 3InSat offers considerable economic potential and further studies should be conducted as soon as the cost-factors database has improved. For this reason DB Netz will participate in further developments of the "virtual balise" concept using GNSS technology. Therefore, as soon as new cost information about the 3InSat system components will be available, the cost-efficiency analysis will be updated. The satellite based train control system 3InSat will be developed further in the framework of the Horizon2020 project ERSAT-EAV; likewise, the cost figures for Eurobalises will be refined. Meanwhile, there will be further investigations about finding a more cost efficient alternative for the train radio and data communication in Germany, since GSM-R will be obsolete in the next decade.

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ZUSAMMENFASSUNG

Analyse der Wirtschaftlichkeit eines Systems zur satellitengestützten Zugortung

Die DB Netz AG ist an kosteneffizienten, sicheren und zuverlässigen Alternativen für konventionelle Systeme der Leit- und Sicherungstechnik für regionale Strecken in Deutschland interessiert. Das Projekt 3InSat hat als Ziel, einen Demonstrator zu entwickeln, welches Satellitennavigation verwendet und SIL-4-Anforderungen und Kompatibilität zu dem ERTMS-Standard erfüllen soll. Im Rahmen dieses Projekts haben die DB Netz und das Deutsche Zentrum für Luft- und Raumfahrt (DLR) eine Wirtschaftlichkeitsanalyse im Vergleich zu den alternativen Systemen ERTMS-Regional, ETCS-Level 2 ohne konventionelle Lichtsignale und dem konventionellen Signalsystem (Ks-System) erstellt. Für die Analyse wurden generische Streckenstandards der DB verwendet, um die Ergebnisse auf die entsprechenden Teile des DB-Streckennetzes übertragen zu können. Für die jeweiligen Referenzstrecken und die Ausrüstungsvarianten wurden mittels der Nettobarwertmethode die Kosten berechnet und vergleichend dargestellt. Ergebnis der Kostenrechnung und der anschließenden Sensitivitätsanalysen ist, dass 3InSat ein hohes Kosteneinsparpotential bietet, welches maßgeblich aufgrund des Prinzips, physische Eurobalisen durch virtuelle zu ersetzen, zurückzuführen ist. Da aufgrund des Entwicklungsstadiums von 3InSat noch viele Annahmen getroffen werden mussten, wird die Wirtschaftlichkeitsanalyse fortwährend aktualisiert.