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FEASIBILITY ANALYSIS OF GSM-R SYSTEM FOR RAILWAYS IN INDONESIA: CASE STUDY OF JAKARTA BANDUNG HIGH SPEED TRAIN

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Abstract: High-speed railway technology development necessitates the development of a communication system that supports various components of train operation facilities, such as train control, safety communication, and others. The construction of fhigh-speed railway in Indonesia in the Jakarta-Bandung area uses the Chinese Train Control System (CTCS) Level 3 signaling system, which makes the Global System for Mobile Communication-Railway (GSM-R) a wireless signaling network system. Because there are already existing GSM-based public telecommunications services, known as public GSM, on the same frequency used by a number of cellular operators in Indonesia, the use of GSM-R poses implementation challenges. This will result in reduced service quality and revenue for protected cellular network operators due to the use of these frequency bands to support the operation of high-speed railway services in Indonesia. In this study, an evaluation was carried out to look for other potentials from using the GSM 900 MHz frequency band, which can be used as an option to be implemented on high-speed trains in Indonesia. The research begins with calculating the estimated potential loss of revenue from using telecommunications network operators. This data will be analyzed in terms of the economic feasibility of several other frequency band choices for implementing the GSM 900 MHz frequency band on high-speed trains in Indonesia, so that it is hoped that this will become a new consideration that can become a solution and recommendation in the application and use of GSM-R technology in Indonesia.

Keywords: High-Speed Railway, GSM-R, Frequency

1. INTRODUCTION

Trains as a mode of mass transportation are said to have become a major necessity for countries that have densely populated populations. One of the benefits of transportation modes for the community is punctuality and short travel time, answering the needs of the community, fast trains can be a solution to the needs of the community. Railway transportation modes are increasing in need, especially in Indonesia as shown in Figure 1. (Hammi et al., 2009).

Figure 1. Number of Train Passengers in 2012-2022

Answering all the needs of the community, fast trains can promise convenience to the community regarding the efficiency of time and travel time expected from public transportation modes, because the high speed and punctuality factor in transportation modes will increase customer satisfaction and help improve the socio-economic conditions of the community. In addition to the efficiencies provided by high-speed modes of transport, there are significant challenges in terms of investment, technology, industry and the environment. The development of high-speed train technology requires a reliable communication system because it is very important for various components such as train control, communication, and others. *Real-time* information on railway communication systems is an absolute must. More and more aspects are automated with *mobile* devices to improve the quality of communication systems in transportation modes to improve passenger service reliability. Globally, the *future rail mobile communication system* or commonly called FRMCS is predicted to be the future technology of high-speed train signaling that will replace GSM-R after the completion of standardization and *real field* experiments in 2023-2034. The FRMCS system has not yet been implemented in Indonesia and is still in the planning and development stage. Therefore, the frequency to be used for FRMCS in Indonesia still has to be determined and further discussed by relevant parties, as it needs to require significant infrastructure updates and investments. At present the technology most likely to be implemented in high-speed train signaling is GSM-R technology. The challenges that will be the solution are in terms of flexibility of frequency use, device presence, network model, security, operational procedures and the availability of appropriate technology in the future. The limiting things are aspects of system migration, the presence of frequency, connectivity capabilities, the need to be free from interference, infrastructure reuse seen from economies of scale.

GSM-R is designed to meet the needs of better and sophisticated communication in the railway sector in Indonesia today, especially in high-speed trains, the GSM-R system supports the fulfillment of the needs of railway operation facilities including in terms of improving safety and efficiency of operations on train travel. This technology will enable faster, more reliable, and safer exchange of data and voice between trains, stations, and operations control centers. (Railway Telecommunications, 2010)

The Jakarta-Bandung high-speed train project is planned to use the *Chineese Train Control* System (CTCS) level 3 signaling system which makes *the Global System for Mobile Communication – Railway* (GSM-R) a *wireless signaling network system*. Based on the device structure of the CTCS Level 3 signaling system in figure 2.

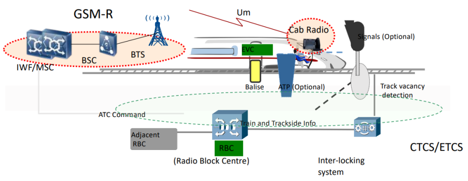

Figure 2. GSM-R System Overview
(Source: Detail Design Document CRSC for GSM-R)

Based on figure 1.2 GSM-R is a digital mobile communication system specifically for railways based on GSM technology and it can be seen that GSM-R is a radio communication system or technology used as a wireless signaling network *that connects signaling devices on trains with the* operation command center *and of course as an* interlocking *system* which is used to cross high-speed trains in Indonesia in the Jakarta-Bandung area. In various countries in Europe, the frequency bandwidth for GSM-R is 4MHz at 876-880 MHz for uplink and 921-925 for downlink.

The use of GSM-R for high-speed trains is the first use of radio communication for railways that use GSM frequencies as radio communication for train signaling in Indonesia. The use of GSM-R on cross-railways in Indonesia, brings challenges in its implementation, considering the existence of existing public telecommunications services that are also GSM-based, which is referred to as public GSM on the same frequency and there is no regulation or legal umbrella from the Indonesian government to regulate the use of radio communication in the GSM frequency band for the needs of train operations, especially high-speed trains.

The implementation of telecommunication technology in railways, especially for high-speed trains, has strict requirements in terms of *Quality of* Service (QoS) such as data speed, transmission delay, bit error rate (BER) and others. *Global System for Mobile Communication – Railway (GSM-R)* is one of the selected technologies following the CTCS Level 3 technology standard to be implemented.

Globally GSM-R has been used in more than 70,000 km of railway lines, 22,000 of which are high-speed rail lines and no train lines that use GSM-R technology in radio communication in Indonesia. The frequency band that will be used in the high-speed train signaling system in Indonesia is 900 MHz which has been used by a number of cellular operators in Indonesia. Figure 1.3 shows the arrangement of frequency blocks used by existing cellular operators in Indonesia.

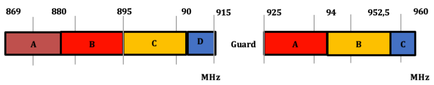

Figure 3. Arrangement of Frequency Blocks of Cellular Operators in Indonesia at 900 MHz

The selection of frequency bands for the GSM-R system in high-speed train signaling in Indonesia will have different impacts, especially in various aspects, especially in terms of financial impact. Based on table 1.1, there are 3 choices of frequency band pairs that the author will examine for the use of GSM frequencies on Fast Trains in Indonesia.

Table 1. Choice of pairs Use of frequency bands for high-speed trains

Choice	Frequency Band Pairs (MHz)	Basis of Selection
A	880 – 884 / 925 - 929	Retrieve the endpoint of the frequency block of one of the affected mobile operators
B	885 – 889 / 930 - 934	Following GSM-R implemented in China
C	891 – 895 / 936 – 940	Retrieve the endpoint of the frequency block of one of the affected mobile operators

The implementation of the GSM-R system in Indonesia will lead to a form of cooperation between train operators and cellular operators that has never been done before, because the two operators have two different business licenses. Therefore, it is necessary to study the economic feasibility of several frequency band options, by comparing the potential minimum revenue loss from frequency band pairs from affected cellular operators, and it is important to conduct research on the implementation of GSM-R frequencies in Indonesia as an illustration for decision making in implementing the next GSM-R system, so that various parties can find out how deep the GSM-R system is. The implementation of the GSM-R system is beneficial for the business of each authority when compared to the cost requirements incurred for the implementation of the GSM-R system in Indonesia.

2. METHODOLOGY

In the analysis process, information will be collected from literature studies in the form of scientific journals, papers and interviews from parties related to the data needed for research, namely the analysis of the feasibility level of the GSM-R system for railways in Indonesia: A Case Study of the Jakarta Bandung High Speed Train. In the initial process, the variables from literature studies and interviews in general will be brought to experts or several experts to be validated and clarified by asking "Do you agree that the variables mentioned and attached below are factors that affect the analysis of the feasibility level of implementing the GSM-R system in high-speed train operations in Indonesia (Jakarta-Bandung Area)"?

Furthermore, the expert or experts are asked to fill out responses or proposals and inputs that can express the expert's perception of the parameters of these variables. The expert or experts have the right to add and subtract variables that the researcher previously attached. The data from the expert or experts is then processed in such a way as to one of the methods, so that the resulting variables are factors that can affect the analysis of the feasibility level of implementing the GSM-R system in the operation of high-speed trains in Indonesia, the Jakarta-Bandung area.

Research Variables

Research variables are everything in any form set by the researcher to be studied so that information is obtained about it, then conclusions are drawn. In quantitative research, variables are divided into three types of variables (Prasetyo &; Miftahul, 2007), namely: (Sugiyono , 2017)

a. Independent variables, variables that exist or occur before the dependent variable. Variables that explain the occurrence of focus or research topics
b. Dependent variable (bound), a varibael that is influenced by an independent variable. Variables described in the focus or research topic.
c. Control variables, varibael that may be present in the study. Consists of three types, namely *antecendent variables* – variables that precede independent variables; intervening variables-variables that are between the independent variable and the dependent variable, the free variable affects the intermediate variable first; suppressor variable – a variable that changes the relationship, causing a relationship between the independent variable and the dependent variable that did not previously exist; Disorter variable – a variable that changes the relationship between an independent variable and a bound variable that was previously positive to negative. In this study, only 2 variables will be used, namely independent variables and dependent variables.

The independent variable or variable IN is a variable that causes or causes changes in variable Y or variable OUT.

Data Collection Methods

The technique used in collecting data in this study is to apply the concept of literature study which contains theories, concepts and variables. This information is sourced from scientific journals, books, articles and other sources of information that are useful in supporting research. The primary data obtained from this study is primary data from the results of field reviews by collecting data from interviews. While the secondary data obtained from this study is the result of collecting data or information obtained from the results of literature studies, such as scientific journals, articles, and previous studies that have a relationship. Validation of variables in this study will be carried out by experts or experts. These experts will be drawn from several practitioners who have competence in the field of telecommunications and in the field of railways.

Questionnaires are used for initial validation and final validation of experts or experts by paying attention to sampling techniques. This questionnaire is distributed to experts and experts as predetermined respondents to seek information about the problem under study. The following are the stages of the development of the questionnaire carried out:

a. Stage 1: expert initial validation of the questionnaire that has been prepared to 3 experts or experts. Validation carried out at the initial stage using a questionnaire model (Ridwan, 2009). The questionnaire used is a closed questionnaire, which is a questionnaire that is presented in such a form that respondents are asked to choose one answer that is in accordance with their opinions and perceptions by determining the answer choices "agree" and "disagree" in the answer column provided.
b. Stage 2: expert final validation of the data that has been collected and processed, then compiled and given to 3 experts or experts for validation. The validation used at the final stage uses a questionnaire model (Ridwan, 2009). The questionnaire used is a closed questionnaire, which is a questionnaire that is presented in such a form that respondents are asked to choose one answer that suits their personal perceptions and opinions by providing "agree" and "disagree" answer choices in the answer column provided.

The qualifications of experts or experts who will fill out the questionnaire are as follows:

- Practitioners
- Minimum S1 Education
- Minimum 15 years experience in signaling, especially in telecommunications with a good reputation in the company.

3. RESULT AND DISCUSSION

Jakarta and Bandung are one of the economic centers in Indonesia. Seeing the strategic economic potential of the Jakarta and Bandung areas, the Government decided to carry out infrastructure development in the form of high-speed trains between Jakarta and Bandung with the aim of increasing the growth of economic equity, the tourism sector, etc. in the Jakarta and Bandung areas covering the cities passed by the high-speed rail line, namely Bekasi Regency and City, Purwakarta Regency, and Bandung Regency. Seeing this positive potential, the Jakarta-Bandung Fast Train is the right choice for the Indonesian people which is realized by government programs through the National Strategic Project as a manifestation of mass transportation modernization in Indonesia starting from the Jakarta-Bandung area in building intercity connectivity between provinces, and regional development *(Transit Oriented Development*).

The plan to implement the GSM-R system on the Jakarta Bandung Fast Train using frequency bands that have been used by existing services needs to be studied and analyzed on the use of these frequencies, in order to support the telecommunications system in the operation of the Jakarta Bandung Fast Train.

The use of GSM-R in Indonesia is closely related to the determination of existing cellular operator services that will become inactive due to these public GSM services. The existing Frequency band service was replaced by a special GSM service for high-speed train operations. Figure 3.2 illustrates the condition of existing public GSM services in the Jakarta-Bandung area.

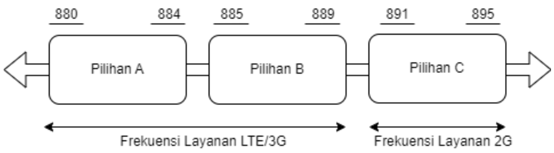

Figure 4. Existing public GSM services at frequencies 880-895 MHz

When viewed in figure 3.2 option A and option B will have the same impact, namely the inactivity of cellular operator data services, while option C will cause voice and SMS communication services to be disabled, as shown in table 2.1.

Table 2. Impact of GSM-R frequency band selection on existing services

Choice	Impact on services	
	Data Services (LTE/3G)	Voice & SMS Service(2G)
Option A	Inactive	Active
Option B	Inactive	Active
Option C	Active	Inactive

Correspondence from the affected cellular operator, PT. X, regarding the supporting infrastructure of existing services in the safe zone carried out within a safe distance of 19.95 km from the high-speed rail line, data on the number of base stations and the number of cells in the Public GSM network operating in the 900 MHz frequency band were obtained. Data on the replacement cost component of the use of the affected frequency band can be obtained from the components that can be seen in Table 3.

Table 3. Public GSM Infrastructure at 900 MHz Affected

Type of Service	Number of Base Stations	Number of Cells
2G	1604	4787
3G	14	41
4G	3726	11027
Total	5344	15855

This research stage is a working design to analyze potential losses and evaluate the economic feasibility of several GSM frequency band service options that will be used in high-speed train operations in Indonesia. There are two calculation flows carried out according to the impact of affected services on the existing service frequency band, namely:

1. The calculation of voice and SMS service inactivity, a variable in the calculation of potential revenue loss in mobile operators affected by voice and SMS service inactivity, is described in the following flow diagram.

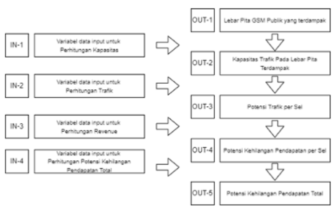

Figure 5. Input Variables and Output Variables in the Calculation of Potential Voice & SMS Service Revenue Loss

The calculation begins by calculating the capacity of service traffic that can run on the frequency bandwidth to be used for GSMR system services, by entering variables that are appropriate to existing conditions and have been validated by experts, to obtain the value of potential revenue loss due to inactivity of voice and SMS services in the affected frequency bands.

Table 4. Input Data and Calculation Results of Potential Voice and SMS Service Revenue Loss

Data	Variabel	Nilai	Satuan /Keterangan
OUT-1	Lebar Pita GSM Telkomsel terdampak	5.000,00	KHz
IN-1	Standar Lebar Pita 1 Kanal GSM	200,00	Khz
	Jumlah carrier	25,00	
	Jumlah carrier untuk signalling	4,00	
	Jumlah carrier untuk trafik	21,00	
	Junlah time slot per carrier GSM	8,00	
	Jumlah kanal trafik pada sel	168,00	Per sel
	Grade of Service (Standar PM Kualitas layanan)	5,00	Persen
	Total trafik pada jam sibuk (Rumus Erlang B)	165,30	Erlang/sel
	Persentase trafik suara	95,00	persen
	Persentase trafik SMS	5,00	persen
OUT-2	Trafik Suara	157,04	Erlang/sel
	Trafik SMS	8,27	Erlang/sel
IN-2	Jumlah hari dalam satu tahun	365,00	Hari
	Jumlah hari sibuk dalam 1 tahun	260,00	Hari
	Jumlah jam sibuk dalam 1 hari	4,00	Jam
	Jumlah jam idle	4,00	Jam
	Jumlah jam non idle di luar jam sibuk	16,00	Jam
	Persentase trafik rata-rata di luar jam sibuk	20,00	Jam
	Jumlah SMS per jam untuk kanal GSM	27.067,00	Persen
	Persentase trafik rata-rata di luar hari sibuk	10,00	SMS/Jam
OUT-3	Total trafik suara per hari	1.130,65	Erlang/hari
	total trafik SMS per hari	59,51	Erlang/hari
	Total trafik suara per sel per hari	847,99	Erlang/sel/hari
	Total trafik SMS per sel per tahun	44,63	Erlang/sel/hari
	Total trafik suara per sel per tahun	229.381,02	Erlang/sel/tahun
	Total trafik SMS per sel per tahun	12.072,69	Erlang/sel/tahun
	Menit trafik suara per sel per tahun	8.588.025,56	menit/sel/tahun
	Jumlah SMS per sel per tahun	3.267,71	SMS/sel/tahun
IN-3	Tarif suara per menit (analisis internal PT.X)	116,00	Rupiah/menit
	Tarif SMS (analisis internal PT.X)	62,00	Rupiah/SMS
OUT-4	Total menit trafik suara per tahun	8.588.026,00	menit/tahun
	Total SMS per tahun	3.267.714,00	SMS/Tahun
	Potensi kehilangan pendapatan suara/tahun	996.210.965,00	Rupiah/Tahun
	Potensi kehilangan pendapatan SMS/TAHUN	202.598.255,00	Rupiah/Tahun
IN-4	Jumlah sel terdampak	4.787,00	sel
out-5	Total menit trafik suara per tahun	41.110.878.343,00	menit/tahun
	Total SMS per tahun	15.642.545.885,00	SMS/Tahun
	Potensi kehilangan pendapatan suara/tahun	4.768.861.887.753,00	rupiah/tahun
	Potensi kehilangan pendapatan SMS/tahun	969.837.844.893,00	rupiah/tahun
	Total potensi kehilangan pendapatan per tahun	5.795.453.156.874,00	rupiah/tahun

2. The calculation of data service inactivity, a variable in the calculation of potential revenue loss for mobile operators affected by data service inactivity, is described in the following flow diagram:

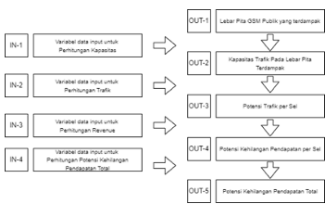

Figure 6. Input Variables and Output Variables in the Calculation of Potential Data Service Revenue Loss

The calculation begins by calculating the capacity of service traffic that can run on the frequency bandwidth that will be transferred to GSMR services, by entering variables that are appropriate to existing conditions and have been validated by experts, to obtain the value of potential revenue loss due to inactivity of data services in the affected frequency bands.

Table 5. Input Data and Calculation Results of Potential Data Service Revenue Loss

Data	Variabel	Nilai	Satuan/ Keterangan
OUT-1	Lebar Pita GSM Telkomsel terdampak	10.000,00	KHz
IN-1	Throughput efektif LTE per sel	75.000.000,00	Bps
OUT-2	Payload data terdampak	4.703.684.210.526,00	bit
IN-2	Jumlah hari dalam satu tahun	365,00	Hari
	Activity Factor	260,00	
	Active Hours (survey APJII 2022)	17,50	Jam
OUT-3	Payload data per sel terdampak per hari	470,00	GB
	Payload data per sel terdampak per tahun	171.686,00	GB
IN-3	Tarif data per GB (analisis internal PT.X)	6.500,00	Rupiah/Gb
OUT-4	Potensi kehilangan pendapatan per sel	1.115.949.079,00	rupiah/tahun
IN-4	Jumlah sel terdampak	11.027,00	sel
out-5	Payload data sel terdampak per hari	5.186.753,00	menit/tahun
	Payload data sel per tahun	1.893.164.691,00	SMS/Tahun
	Total Potensi kehilangan pendapatan per tahun	12.305.570.491.500,00	rupiah/tahun

By looking at the amount of calculation of potential loss of revenue from existing public services, for both scenarios of inactivity of voice & SMS services and inactivity of data services, it can be concluded that the GSMR system is implemented in the existing frequency bands for voice and SMS services, as shown in table 3.7.

Table 6. Total Financial Impact of GSMR Implementation

No	Variabel	Pilihan A/B Layanan Data Non-Aktif	Pilihan C Layanan Suara &SMS Non akatif	Satuan/ Keterangan
1	Biaya Pembangunan Infrastruktur Pengganti	8.678.800.000.000,00	3.721.280.000.000,00	rupiah
2	Potensi Kehilangan pendapatan per tahun dari layanan yang di non-aktifkan	12.305.570.491.500,00	5.795.453.156.874,00	rupiah
3	**Total dampak implementasi GSM-R**	20.984.370.491.500,00	9.516.733.156.874,00	Rupiah

The total transfer of GSM service functions to GSMR services consists of the total revenue loss component from services that need to be inactivated and the total development of infrastructure costs to replace public GSM BTS, the total impact of GSMR implementation for each GSMR frequency band option is summarized in table 3.7. A detailed summary of the total financial impact of GSMR implementation on 891-895 MHz and 936-940 MHz frequency band pairs is that option C has less financial impact than other frequency band pair options. So it was found that voice and sms services have a smaller potential loss impact than the choice of using existing frequency bands of data services. TheGSM-R system for the Jakarta Bandung High Speed Train is a critical step in ensuring the safety, efficiency, and effectiveness of the high-speed rail line. By evaluating technical, operational, economic, safety, regulatory, and social aspects, this analysis provides valuable insights into the benefits and challenges associated with the adoption of GSM-R technology in the context of Indonesian railways. The results of this analysis will guide decision makers in making informed choices regarding GSM-R implementation and contribute to the overall success of the high-speed rail project.

4. CONCLUSION

Based on the results of the study, it can be concluded that the Fast Train project Case study for Jakarta Bandung, in an effort to implement the implementation of the *Global System Mobile – Railway* (GSM-R) system using 900 MHz frequency band services as a *wireless signalling network* from the operation of CTCS Level 3 on high-speed train systems in Indonesia, needs to use frequency service bands that are different from the technical characteristics of GSMR implemented in China, because it is necessary to take into account the impact of potential loss of revenue on existing public frequency band services affected by cellular network operators.

By considering various aspects such as technical, operational, economic, security, and regulatory, the results of this analysis will assist decision makers in making decisions or as an initial guide for determining the selection of related technologies to develop telecommunication system services in the next high-speed train operation in Indonesia.

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