Improving Ballastless Track Quality Using Project Quality Management and SmartPLS

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Abstract - Transportation is still a significant problem in Indonesia. Indonesians prefer to use private vehicles for daily mobility purposes because public transportation lacks safety and comfort and has a longer trip duration. This issue causes congestion and air pollution problems. Hence, sustainable rail-based public transportation is recommended. Light Rail Transit (LRT) tends to be congestion-free and has a relatively shorter travel time with a large passenger capacity. Most LRT track constructions use the ballastless track. However, this track construction is still new in Indonesia. The research aimed to determine the most important factors in improving ballastless track construction performance on LRT. The research referred to the existing LRT construction in Indonesia using Lean Construction (LC) and Project Quality Management (PQM) approaches. Statistical science approach with SmartPLS software was also used in data processing and modeling the relationship between variables. The research was conducted by distributing questionnaires to determine the most important factors in improving the quality of ballastless tracks with variables and indicators extracted from LC and PQM methods. From five tested hypotheses, only one hypothesis is accepted. Quality control has a positive effect on track quality. It is also found that quality control becomes the most important variable in improving ballastless track quality.

Keywords: ballastless track quality, Project Quality Management, Lean Construction, SmartPLS

I. INTRODUCTION

Transportation is still a major problem in Indonesia. Indonesians prefer to use private vehicles for daily mobility purposes because public transportation lacks safety and comfort and has a longer trip duration. This issue causes congestion and air pollution problems. Sianipar (2019) stated that total trips in Greater Jakarta (Jakarta, Bogor, Depok, Tangerang, and Bekasi) reached 47,5 million trips per day in 2015. However, 50% of the trips were through traffic from Bogor, Depok, Tangerang, and Bekasi to Jakarta. Therefore, road performance was definitely low because the volume to capacity ratio was close to 1.

Moreover, Bongso, Sendow, and Manoppo (2019) mentioned that the Volume Capacity Ratio (VCR) level on several roads in Manado City, such as Jalan Piere Tendean, with a VCR of 0,89. It indicated a high traffic density using Level of Service (LOS). Both Sianipar (2019) and Bongso *et al.* (2019) recommended sustainable rail-based public transportation, namely Light Rail Transit (LRT). It tended to be congestion-free and had a relatively shorter travel time with a large passenger capacity.

Each train has its problems, such as the train getting off the railroad, the collapsed railroad, the train collision, and so on (Bakhrakh, 2014). At the very least, these problems result in physical and financial losses. Such problems can also cause immeasurable human losses. Based on train accident statistics from Statistics

of Railway Accident (2020), train derailment ranks second after the railway crossing problem, which is the biggest cause of train accidents in Japan. Statistical data from Indian Railways also shows that most train accidents occur due to train derailments and crossing accidents (level crossing accidents). In contrast to Japan, India's train derailments are the largest cause of train transportation accidents (Dubbudu, 2016).

Some other accident examples include derailments in Switzerland, Colorado in the United States, and Russia. The general reason for all these problems is that the railway is not in a safe and right condition. Four common conditions can cause problems with the track: incorrect track geometry conditions, incorrect gauge connection, subgrade instability, and ballast instability (Bakhrakh, 2014). Based on data compiled from the Federal Railroad Administration (FRA), as a whole, the top two causes (rail damage and track geometry defects) account for 20% of derailment of freight trains on the mainline. It shows that prevention of these main causes can reduce a substantial risk of slipping (Liu, 2017). It is also confirmed that train track and equipment failure are a major cause of train derailment on straight lines, while money orders are the main cause of derailment in curved lanes or track changes (Liu, Saat, & Barkan, 2012).

Then, Habtamu, Zhao, and Ren (2013) clustered LRT track construction into three major alternatives: ballasted track, prefabricated slab/floating ladder track, and green track. Among those three alternatives track, the green track was found the most suitable track construction for LRT systems. It was a ballastless track with the vegetation layer on top of the concrete surface.

Over the past 20 years, railroad technology has seen an increase in the use of concrete plate technology for transit, commuter, and high-speed rail (Tayabji & Bilow, 2001). A ballastless track is a structural trajectory that the path with a particulate ballast is replaced by a cement base material (concrete or asphalt cement). With the spread of ballastless track technology, the field of concrete applications is expanded to the railroad. However, it is unfortunate that the phenomenon of cracking concrete in the path without ballast has emerged widely in high-speed railroad projects abroad and domestically (Xie, Li, Feng, & Lee, 2009). Track without ballast or ballastless track is already at the forefront of railway engineering. It presents various advantages compared to conventional ballast track. This type of track is usually called "slab track" or "non-ballasted track" (Casal, 2010). Slab track or ballastless track structures (tracks using concrete plates) have been widely used in high-speed railways in Japan, Germany, France, and China. The ballastless slab track shows better stability and durability and has lower maintenance than the ballasted slab track system (Sun, Chen, & Zelelew, 2013). If the track is above the ground, the subsoil must be homogeneous and withstand the imposed burden. Slab layers can be made as precast or in-situ concrete, using more efficient construction methods. The composition of concrete can further reduce construction costs (Smirnova, 2017).

According to Robertson *et al*. (2015) about ballastless track innovation called New Ballastless Track (NBT), from an economic perspective, it has a Return on Investment (ROI) of 10 to 20 years. When adding savings in civil works, some NBT projects will provide lower capital costs than ballasted track. Figure 1 shows an example of the ballastless track construction. A concrete arrangement of concrete sleepers replaces the ballast. There is also continuous concrete, such as a cast road. This type of construction can withstand greater axle loads than ballasted tracks. Hence, it is usually used for high-speed trains. However, there are some Mass Rapid Transit (MRT) or LRT that adopt this system as well.
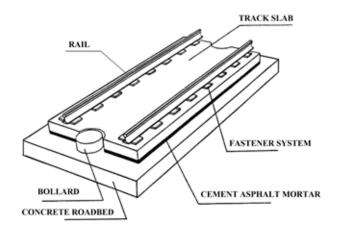

Figure 1 The Sketch of Ballastless Track System
(Source: Yang, Kong, Cai, & Wang, 2016)

The rails on the railway serve as a platform for rolling the train wheels and continuing the load from the train wheels to bearings with a standard of 25 meters. Rail is a significant component of rail transportation, and its integrity is essential to ensure railroad safety. Continuous Welded Rail (CWR) is generally used in ballastless tracks. These rails provide advantages of long service life, low maintenance, and better stability than ballast track (Wang, Liu, Wang, Liang, & Ren, 2016).

Ballastless track uses concrete type bearings. There are two types of concrete bearings: double block concrete blocks (bi-block) and single block concrete (monolithic). Concrete bearings are heavy, which is between 160200 kg. It has better rail stability for the forces at work and is more suitable for trains with large tonnage or high speeds (Fischer, Eller, Kada, & Németh, 2015).

Moreover, there are two types of sleeper systems, namely embedded sleeper systems and non-embedded sleeper systems. The embedded sleeper system is the simplest track slab design. In this system, the ballast is only replaced by Concrete Support Layer (CSL). The bearings are used to adjust the track grid. After

adjusting the geometry, they are cast together with a concrete slab (top/bottom approach). Meanwhile, the non-embedded sleeper system encloses the bearings in the elastomeric hull with an under sleeping pad (sleeping mat). The concrete is poured around, except for the *BetonTragschicht mit Direktauflagerung* (BTD) system. It uses a mono-block sleeper that is only placed on a concrete slab (Matias & Ferreira, 2020).

Next, a fastening system is used to hold the rail element with the slab element. It must be an elastic type that has been proven well under service conditions on continuously welded tracks. The fastening system must have four anchor bolts on each rail seat. The distance between each binder is 0,65 m, in straight and curved alignments. The estimated weight of the binder is 20 kg per binder system. Then, the maximum longitudinal limit per binder system is 13 kN. The goal is rail fasteners. Once installed, they will require minimum maintenance, and parts that fail can be easily replaced during the operating period. It is in accordance with the ability of elasticity that can be given by rail fastening (Karthiga, Selija, Javali, & Elavenil, 2014).

A concrete slab replaces ballasts on the track slab without ballasts. The concrete track support layer and the monolithic concrete slab from the ballastless track system are made in-situ so that a concrete mixture with high workability is needed (Sun *et al.,* 2013). The material and proportion of the determined and used mixture must maintain their integrity and be applicable to protect the corrosion of the embedded metal. The Reactive Powder Concrete (RPC) has better performance than Normal Concrete (NC). The tensile stress simulation is in the appropriate RPC strength capacity. Crack and arch damage in the slab, cement and asphalt mortars, and concrete roads are significantly reduced (Yang *et al.*, 2016).

According to Casal (2010), there are the biggest advantages of ballastless tracks, especially high-speed trains. First, it is the significant reduction in the required maintenance over the life of the track. It leads to higher availability and a substantial reduction in costs around 20–30% compared to traditional ballasted track. Second, there is a significant improvement in track life. Third, there is no drag on the ballast by the high-speed train. Fourth, it has better control of the structural behavior in the tracks in terms of stiffness and stability. In addition, higher lateral resistance is achieved. Fifth, it has substantial weight and height reduction, making this type of solution more desirable on bridges or tunnels.

Pasquire (2012) emphasized that Lean Construction (LC) was an adaptation of Lean production and was based on a philosophy focusing on delivering better value. Moreover, Firoozi and Heravi (2013) suggested that the ultimate goal of LC was to provide value and eliminate or reduce waste. They stressed that the LC method might be implemented to improve the construction process and increase its efficiency.

The Lean approach focuses on continually increasing customer value by identifying and eliminating non-value-added activities that constitute waste. In service organizations, it exists as a methodology for reducing waste (in terms of time) and allowing processes to be more efficient. It requires checking the process from the client's perspective to eliminate waste and inefficiency (Antony, Snee, & Hoerl, 2017). Waste can be defined as work activity that does not add value in transforming inputs into outputs along the value stream. The eliminated waste from the Lean approach is divided into two main categories, namely Type One Waste and Type Two Waste (Gaspersz & Fontana, 2011). Meanwhile, waste variables are grouped into five categories, and the causes of waste are in six categories (Alwi, Mohamed, & Hampson, 2002).

Moreover, the quality method is commonly used to evaluate the quality of railroads include Track Quality Index (TQI), Track Geometry Index (TGI), J Synthetic Coefficient, and European Norms (EN) 13848-5 (Berawi, Delgado, Calçada, & Vale, 2010). Then, Track Recording Car (TRC) is combined with Track Geometry Index (TGI) and *Deutsches Institut für Normung* (DIN) EN 13848-5 by using available data from TRC to determine the geometry quality of the track and its deterioration. The track geometry deviation and irregularities are determined statistically using the TGI and DIN EN 13848-5. The result shows that a comparison between TGI and DIN serves as the basis to determine the stage of deterioration of each track and the effectiveness of interventions (Camacho, Le, Rapp, & Martin, 2016). However, all these methods are only limited to quality assessment without any effort to improve quality.

Project Quality Management (PQM) consists of three processes: quality planning, quality assurance, and quality control. Quality planning guides quality activities in the future. It sets out the requirements and standards that must be met and the needed actions to fulfill them. Meanwhile, quality assurance carries out the planned quality activities and ensures that the project utilizes the needed processes to meet the quality standards and final goods requirements. Quality control ensures that quality assurance activities are carried out in accordance with the quality plan, and the requirements and standards are met (Nicholas & Steyn, 2011).

The constraints faced by the project in the case study are the waste in the construction process, such as activities with no added value and the presence of defective product (slab track points), so that it requires reworking. Based on the mentioned description, the research aims to resolve these problems by applying the concept of quality control with the LC and PQM approach to identify and eliminate waste. The result is expected to improve the quality in the next project.

II. METHODS

The research uses a case study. It takes the case on infrastructure projects, especially railroad. The object of the research is the Jakarta P102 Phase 1 LRT project on the grounds. The research investigates LRT railroad with a slab track system that is cast in-situ. At the time of the research, it is only available in this project.

The research uses a purposive sampling method. The researchers determine the sampling by determining specific characteristics following research objectives. Hence, it can answer the research problems by selecting personnel who are directly involved in the case study project. The respondents are stakeholders who are directly involved in the Jakarta LRT railway development project. The data collection is done by distributing questionnaires with offline and online surveys. About 40 questionnaires were distributed from 10 December 2019 to 19 December 2019. However, 31 questionnaires were returned with a response rate of 77,50%.

Research variable is an attribute or nature or value of people, objects, or activities with certain variations determined by researchers to be studied. Then, conclusions can be drawn, which are divided into independent variables and dependent variables (Sugiyono, 2013). The independent variable (X) is from LC and PQM, and the dependent variable (Y) is the quality of the ballastless track. The variables and number of indicators can be seen in Table 1.

Table 1 Research Variables and Indicators

Code	Variables	Sub Variables	Number of Indicators
X	LC and PQM		
X.1		Lean (Waste)	19
X.2		Quality Planning	14
X.3		Quality Assurance	10
X.4		Quality Control	15
X.5		Quality Improvement	13
Y	Ballastless Track Quality		9

Hypotheses are temporary answers for problems that are still presumptive because they still need to be proven. The presumption answer is a temporary truth, which will be tested with the collected data through research. Testing the hypothesis will produce conclusions to reject or accept the hypothesis (Syafnidawaty, 2020). For the selection to be more detailed and easy, the researchers need an alternative hypothesis (Ha) and the null hypothesis (Ho). Ha is also called the working hypothesis or research hypothesis. Moreover, Ha is the opponent of Ho. Ha tends to be expressed in positive sentences, while Ho is expressed in negative sentences. Based on the variables, the research hypotheses are as follows.

H1 : Lean (LN) affects the ballastless track quality (TQ),
H2 : Quality planning (QP) affects the ballastless track quality (TQ),
H3 : Quality assurance (QA) affects the ballastless track quality (TQ),
H4 : Quality control (QC) affects the ballastless track quality (TQ),
H5 : Quality improvement (QI) affects the ballastless track quality (TQ).

Analysis of the research data uses a statistical approach in the form of reliability, frequency, validation test, and Smart Partial Least Square (SmartPLS) model. According to Haryono (2017), the purpose of PLS is to help researchers for predictive purposes. PLS is a Structural Equation Modeling (SEM) equation model based on components or variants. PLS-SEM focuses on explaining variances rather than covariances, making it a predictive-oriented approach to SEM (Shmueli, Ray, Estrada, & Chatla, 2016). The formal model defines latent variables as the aggregate linear of the indicators. Weight estimates for creating the component score of latent variables are obtained based on how the inner model (the measurement model) and the relationship between indicators and constructs are specified. The result is the residual variance of the dependent variable.

The research is reflective because the latent variable indicator affects the indicator. For this reason, three methods of measurement are used, according to Haryono (2017). First, convergent validity measures the magnitude of the correlation between constructs and latent variables. Second, discriminant validity is carried out to ensure that each concept of each latent variable is different from the other variables. According to Haryono (2017), if the composite reliability value is > 0,7 and Cronbach's alpha is above 0,60, the construct is reliable. If the value is $\geq 1,96$ for t-statistics and $\leq 0,05$ for p-values, the data are valid.

Third, inner models (inner relations, structural models, and substantive theory) describe the relationship between latent variables based on substantive theory. It is evaluated using R-squared for the dependent construct, Stone-Geisser Q-square test for predictive relevance, t-test, and the significance of the structural path parameter coefficients. Interpretation of R^2 value is the same as R^2 linear regression interpretation. It is the magnitude of the variability of endogenous variables that can be explained by exogenous variables. Table 2 shows the assessment criteria for the PLS-SEM model.

To achieve the research objectives and carry out the research systematically, a research flow diagram is needed. The flowchart of the research is illustrated in Figure 2.

Table 2 Assessment Criteria for the Partial Least Square-Structural Equation Modeling (PLS-SEM) Model

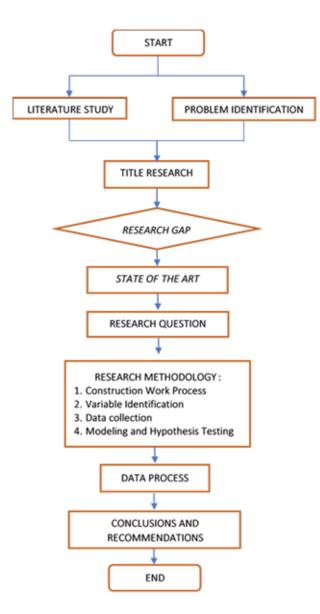| No	Criteria	Description
1	Loading Factor	Loading factor value must be > 0,7. For research at the development stage, a value of 0,50-0,60 is still acceptable.
2	Composite Reliability	Composite reliability measures internal consistency, and its value must be > 0,7.
3	Average Variance Extracted (AVE)	AVE value must be > 0,5.
4	Discriminant Validity	The square root value of AVE must be bigger than the correlation value between latent variables.
5	Cross Loading	Another measure of discriminant validity. It is expected that each block indicator has a higher loading value for each measured latent variable compared to the indicator for other latent variables.

(Source: Haryono, 2017)

Figure 2 Research Flow Diagram

III. RESULTS AND DISCUSSIONS

The relationship of variables and indicators using SmartPLS 3.2.8 is illustrated in Figure 3. It is the preliminary model before the process of elimination or modification of indicators. In preliminary model, there are 19 indicators for Lean, 14 indicators for quality planning, 10 indicators for quality assurance, 15 indicators for quality control, 13 indicators for quality improvement, and 9 indicators for ballastless track quality. The first step in using SmartPLS is testing the measurement model (outer model). The research analyzes convergent validity, discriminant validity, and composite reliability.

Convergent validity of the measurement model using reflective indicators is assessed based on the loading factor of the indicators that measure these variables. After the indicator of the output path coefficient diagram that has a loading factor coefficient below 0,6 is dropped, an analysis is performed again with the PLS software. Then, the indicator above 0,6 is generated in the third model analysis results, as shown in Figure 4. In the research, there are six variables with 80 indicators and a questionnaire scale of one to six. After the output path coefficient indicator, which has a loading factor coefficient below 0,6, is dropped from the diagram of the next study, the researchers modify the model three times. Hence, the remaining indicator with a loading factor above 0,6 is shown in Table 3 (see Appendices).

Next, discriminant validity ensures that each concept of each latent variable is different from the other variables. The model has good discriminant validity if each loading value of a latent variable has the greatest loading value with another loading value of other latent variables. Table 4 (see Appendices) shows the value of cross loading and the existence of good discriminant validity. The correlation value of the indicator to the variable is higher than the correlation value of the indicator with other variables. For example, loading factor of LN.3 (indicator of Lean (waste)) is 0,901 which is higher than other loading factors: quality planning (0,758), quality assurance (0,737), quality control (0,767), quality improvement (0,690), and track quality (0,693).

Then, variables are reliable if they have values above 0,70 for composite reliability, above 0,5 for AVE, and above 0,60 for Cronbach's alpha. The SmartPLS output in Table 5 shows that all variables have composite reliability values above 0,70, AVE above 0,5, and Cronbach's alpha above 0,60. Therefore, it can be concluded that the variables have good reliability.
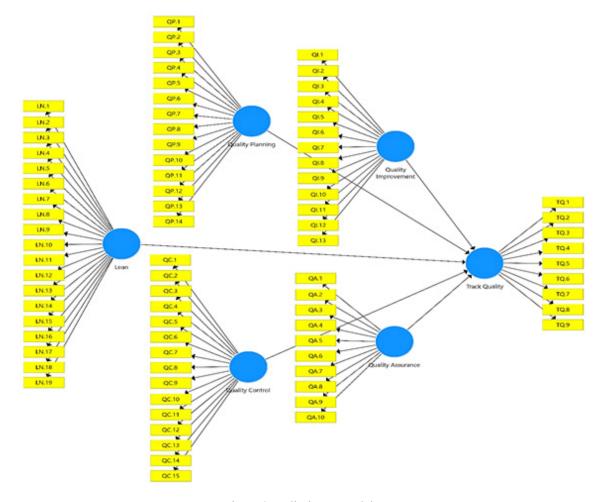

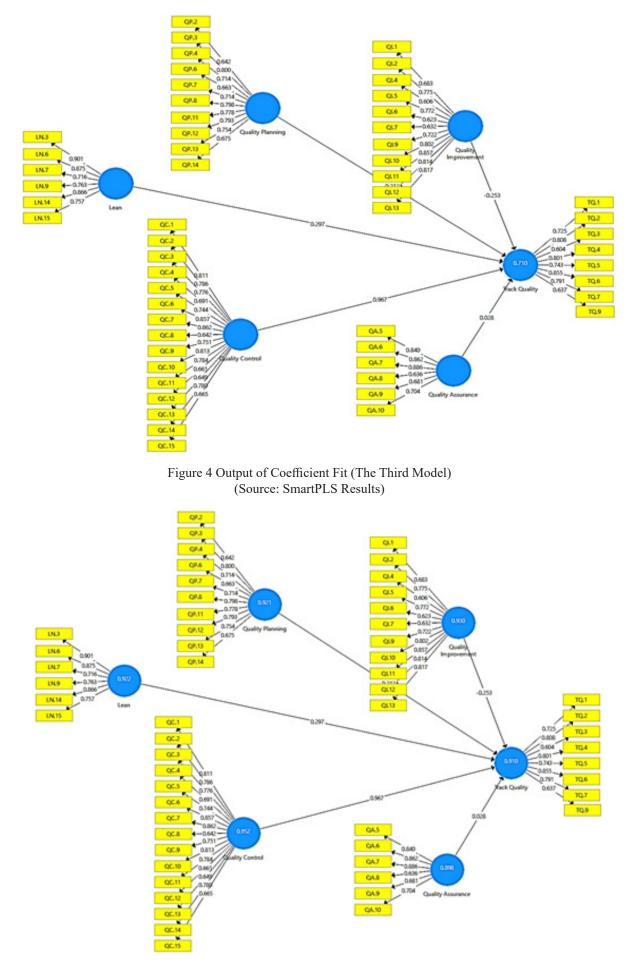Figure 3 Preliminary Model
(Source: SmartPLS Results)

Figure 4 Output of Coefficient Fit (The Third Model)
(Source: SmartPLS Results)

Figure 5 Final Model
(Source: SmartPLS Results)

Table 5 Construct Reliability and Validity

Variables	Cronbach's Alpha	Rho_A	Composite Reliability	Average Variance Extracted (AVE)
Lean (Waste)	0,899	0,919	0,922	0,666
Quality Planning	0,905	0,911	0,921	0,541
Quality Assurance	0,862	0,881	0,898	0,599
Quality Control	0,945	0,952	0,952	0,570
Quality Improvement	0,917	0,926	0,930	0,550
Track Quality	0,887	0,896	0,910	0,563

(Source: SmartPLS Results)

Table 6 Path Coefficients (Original Sample, Mean, Standard Deviation, T-Statistic, and P-Value)

Variables	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T Statistic (|O/STDEV|)	P-Value
LN → TQ	0,297	0,285	0,212	1,400	0,162
QP → TQ	-0,212	-0,238	0,320	0,663	0,508
QA → TQ	0,028	0,066	0,271	0,103	0,918
QC → TQ	0,967	1,018	0,315	3,070	0,002
QI → TQ	-0,253	-0,278	0,273	0,929	0,353

Note: LN= Lean, QP= Quality Planning, QA= Quality Assurance, QC= Quality Control, QI= Quality Improvement, and TQ= Track Quality.

(Source: SmartPLS Results)

Figure 5 is the final model that all indicators are valid and reliable. The model is stated valid as each loading factor value on the indicator (indicated by small arrows) is above 0,6. Moreover, the model is also reliable as the composite reliability value (indicated by a blue circle on each variable) is already above 0,7. In this final model, there are 6 remaining indicators for the Lean variable, 10 remaining indicators for quality planning, 6 remaining indicators for quality assurance, 11 remaining indicators for quality improvement, and 8 remaining indicators for track quality (ballastless track). Meanwhile, there is no eliminated indicator in quality control. It still consists of 15 indicators.

The second step in using SmartPLS is testing the structural model testing (inner model). The structural model in PLS is evaluated using R^2 for the dependent variable. Meanwhile, the value of the path coefficient is for the independent variable, which is assessed for its significance based on the t-statistic value of each path. To assess the significance of the prediction model in structural models, the t-statistic value between the independent and dependent variables in the path coefficient table is used. It is from the SmartPLS output, as shown in Table 6. There are two types of relationship. First, it is positive relationship with track quality, such as Lean with original sample value of 0,297, quality assurance with original sample value of 0,028, and quality control with original sample value

of 0,967. Second, it is negative relationship with track quality. There are quality planning with an original sample value of -0,212 and quality improvement with an original sample value of -0,253.

The third step is hypotheses testing. The hypotheses are tested for correctness by looking at the significance level (p-value). If the significance level from the calculation is below 0,05, and the t-table is above 1,96, the hypothesis is accepted. Vice versa, if the significant level is greater than 0,05, and the t-table is below 1,96, the hypothesis is rejected.

Table 6 shows the result of the hypothesis test. In H1, Ho1 means no effect of Lean on track quality, and Ha1 shows the effect of Lean on track quality. The effect of Lean (original sample) is 0,297. Meanwhile, t-statistic of 1,400 is less than t-table of 1,96. Then, the p-value is 0,162. It is greater than 0,05. The results accept Ho1 and reject Ha1. Thus, it means that Lean has no positive effect on track quality, or H1 is rejected. Lean does not have a significant effect on track quality. Hence, this variable is considered unimportant in improving the ballastless track quality.

In H2, the formulation is as follows. Quality planning has no effect on track quality (Ho2), and there is an effect of quality planning on track quality (Ha2). The results show the value of the original sample of -0,212. T-statistic of 0,663 is less than t-table of 1,96, and p-value of 0,508 is greater than 0,05. It means Ho

is accepted, and Ha is rejected. Thus, quality planning has no positive effect on track quality. H2 is rejected. Quality planning does not have a major effect on track quality. This variable is also not important in improving the ballastless track quality.

In H3, it is formulated that there is no effect of quality assurance on track quality (Ho3), and there is an effect of quality assurance on track quality (Ha3). Path coefficient of quality assurance shows an original sample value of 0,028. T-statistic of 0,103 is less than t-table of 1,96. Then, p-value of 0,918 is greater than 0,05. The results accept Ho and reject Ha. It implies that quality assurance has no positive effect on track quality. H3 is rejected. Hence, this variable is not important in improving the ballastless track quality.

In H4, Ho4 means no effect of quality control on track quality, and Ha4 shows an effect of quality control on track quality. The results have an original sample value of 0,967. T-statistic of 3,070 is greater than the t-table of 1,96. Then, p-value of 0,002 is less than 0,05. Ho is rejected, and Ha is accepted. Quality control has a positive effect on track quality. H4 is accepted. Hence, quality control is important in improving the quality of ballastless track.

In H5, the formulation is as follows. There is no effect of quality improvement on track quality (Ho5), and there is an effect of quality improvement on track quality (Ha5). Path coefficient shows the quality improvement effect (original sample) of -0,253. T-statistic of 0,929 is less than t-table of 1,96. Meanwhile, p-value is 0,353. It is greater than 0,05. The results accept Ho5 and reject Ha5. Quality improvement has no positive effect on track quality. H5 is rejected. Quality improvement does not have a major effect on track quality. Therefore, this variable is not important in improving ballastless track quality.

Based on the questionnaire survey results and SmartPLS, the essential variable in improving the quality of the ballastless track is quality control. It consists of 15 factors that can be used as a reference at the improvement stage. The indicators can be divided into three stages. First, it is monitoring (inspection) before carrying out the work. It consists of calibrating the measurement system (including the measuring instrument) that will be used in work, inspecting the specifications of incoming materials that will be used during the construction process, monitoring the process that has been improved and continue to improve it, and creating a measurement standard to maintain process performance.

Second, it is monitoring (inspection) during work execution (in the process). It consists of reviewing and inspecting each work progress, delivering the results of progress in the implementation of work, implementing every process control and work monitoring, identifying the most potential problems that may occur during the execution of the work, determining the strategy that will be used to maintain the improvement process, inspecting every activity that will be and is carried out so that it always meets the requirements, and identifying the specific actions

and tools to support the objectives or improvements.

Last, it is monitoring (inspection) after the work is done. It consists of comparing the results of each work between the plan and its realization, defining a valid and reliable system, interpreting the difference between actual performance and planned performance, and conducting a final inspection of the work results.

IV. CONCLUSIONS

Five variables are tested to find the most important factors in improving ballastless track quality. Based on the questionnaire results using SmartPLS, quality control positively affects the ballastless track quality. Hence, it is the most important factor in improving the ballastless track quality by referring to the 15 indicators in the variable. The indicator is divided into three parts of activities: monitoring before carrying out the work, monitoring during work execution (in the process), and monitoring after the work is done.

There are several limitations in the research. First, the research object is the ballastless track railway construction project that has been completed. However, there are no other similar ongoing projects, so the researchers cannot do the field validation. Second, combining the two quality methods of PQM and LC to improve the ballastless track quality is still relatively new for ballastless track construction. Therefore, for further research, it is highly recommended to implement the research results in a similar project that is currently running. The future researcher can also combine it with the Six Sigma method at the improvement stage. From this stage, it can investigate whether there is an improvement in quality by referring to the number of reduced defects so that quality can be improved continuously.

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APPENDICES

Table 3 Outer Loadings (Measurement Model)

Variables	Preliminary Model	Model 2	Model 3 (Final)
Lean			
LN.1 <- LN	0,404	-	-
LN.2 <- LN	0,633	0,600	-
LN.3 <- LN	0,875	0,894	0,901
LN.4 <- LN	0,553	-	-
LN.5 <- LN	0,314	-	-
LN.6 <- LN	0,783	0,841	0,875
LN.7 <- LN	0,696	0,735	0,716
LN.8 <- LN	0,617	0,541	-
LN.9 <- LN	0,703	0,735	0,763
LN.10 <- LN	0,449	-	-
LN.11 <- LN	0,582	-	-
LN.12 <- LN	0,425	-	-
LN.13 <- LN	0,557	-	-
LN.14 <- LN	0,856	0,883	0,866
LN.15 <- LN	0,719	0,757	0,757
LN.16 <- LN	0,314	-	-
LN.17 <- LN	0,306	-	-
LN.18 <- LN	0,552	-	-
LN.19 <- LN	0,195	-	-
Quality Planning			
QP.1 <- QP	0,514	-	-
QP.2 <- QP	0,632	0,641	0,642
QP.3 <- QP	0,796	0,803	0,800
QP.4 <- QP	0,665	0,709	0,714
QP.5 <- QP	0,589	-	-
QP.6 <- QP	0,673	0.670	0,663
QP.7 <- QP	0,720	0,718	0,714
QP.8 <- QP	0,797	0,803	0,798
QP.9 <- QP	0,568	-	-
QP.10 <- QP	0,616	0,594	-
QP.11 <- QP	0,769	0,779	0,778
QP.12 <- QP	0,811	0,795	0,793
QP.13 <- QP	0,690	0,749	0,754
QP.14 <- QP	0,673	0,667	0,675
Quality Assurance			
QA.1 <- QA	0,560	-	-
QA.2 <- QA	0,554	-	-
QA.3 <- QA	0,633	0,581	-
QA.4 <- QA	0,668	0,604	-
QA.5 <- QA	0,761	0,807	0,840
QA.6 <- QA	0,774	0,822	0,862
QA.7 <- QA	0,829	0,862	0,886
QA.8 <- QA	0,695	0,677	0,636
QA.9 <- QA	0,604	0,616	0,681
QA.10 <- QA	0,731	0,726	0,704

Table 3 Outer Loadings (Measurement Model)
(continued)

Variables	Preliminary Model	Model 2	Model 3 (Final)
Quality Control			
QC.1 <- QC	0,811	0,811	0,811
QC.2 <- QC	0,787	0,786	0,786
QC.3 <- QC	0,775	0,776	0,776
QC.4 <- QC	0,693	0,691	0,691
QC.5 <- QC	0,745	0,744	0,744
QC.6 <- QC	0,857	0,857	0,857
QC.7 <- QC	0,862	0,862	0,862
QC.8 <- QC	0,638	0,642	0,642
QC.9 <- QC	0,749	0,751	0,751
QC.10 <- QC	0,812	0,813	0,813
QC.11 <- QC	0,783	0,784	0,784
QC.12 <- QC	0,661	0,661	0,661
QC.13 <- QC	0,649	0,649	0,649
QC.14 <- QC	0,779	0,780	0,780
QC.15 <- QC	0,667	0,665	0,665
Quality Improvement			
QI.1 <- QI	0,682	0,686	0,683
QI.2 <- QI	0,776	0,777	0,775
QI.3 <- QI	0,497	-	-
QI.4 <- QI	0,629	0,615	0,606
QI.5 <- QI	0,785	0,773	0,772
QI.6 <- QI	0,628	0,623	0,623
QI.7 <- QI	0,616	0,623	0,632
QI.8 <- QI	0,610	0,592	-
QI.9 <- QI	0,723	0,724	0,722
QI.10 <- QI	0,806	0,807	0,802
QI.11 <- QI	0,833	0,848	0,857
QI.12 <- QI	0,792	0,804	0,814
QI.13 <- QI	0,808	0,822	0,817
Track Quality			
TQ.1 <- TQ	0,720	0,725	0,725
TQ.2 <- TQ	0,793	0,808	0,808
TQ.3 <- TQ	0,607	0,693	0,604
TQ.4 <- TQ	0,796	0,801	0,801
TQ.5 <- TQ	0,745	0,745	0,743
TQ.6 <- TQ	0,857	0,856	0,855
TQ.7 <- TQ	0,788	0,791	0,791
TQ.8 <- TQ	0,504	-	-
TQ.9 <- TQ	0,646	0,637	0,637

Note: LN= Lean, QP= Quality Planning, QA= Quality Assurance, QC= Quality Control,
QI= Quality Improvement, and TQ= Track Quality.

(Source: SmartPLS Results)

Table 4 Discriminant Validity Value (Cross Loading)

No	Indicators	Lean - Waste (X1)	Quality Planning - PQM (X2)	Quality Assurance - PQM (X3)	Quality Control - PQM (X4)	Quality Improvement - PQM (X5)	Track Quality (Y)
1	LN.3	0,901	0,758	0,737	0,767	0,690	0,693
2	LN.6	0,875	0,662	0,665	0,641	0,620	0,607
3	LN.7	0,716	0,545	0,640	0,607	0,634	0,387
4	LN.9	0,763	0,514	0,557	0,493	0,396	0,663
5	LN.14	0,866	0,597	0,634	0,625	0,651	0,544
6	LN.15	0,757	0,358	0,428	0,450	0,425	0,440
7	QP.2	0,427	0,642	0,464	0,570	0,502	0,456
8	QP.3	0,407	0,800	0,555	0,636	0,553	0,399
9	QP.4	0,521	0,714	0,533	0,480	0,381	0,387
10	QP.6	0,425	0,663	0,657	0,604	0,180	0,390
11	QP.7	0,374	0,714	0,568	0,622	0,611	0,374
12	QP.8	0,398	0,798	0,615	0,701	0,596	0,371
13	QP.11	0,622	0,778	0,672	0,710	0,784	0,501
14	QP.12	0,617	0,793	0,719	0,627	0,579	0,505
15	QP.13	0,694	0,754	0,665	0,689	0,630	0,530
16	QP.14	0,593	0,675	0,658	0,597	0,609	0,636
17	QA.5	0,447	0,664	0,840	0,706	0,621	0,616
18	QA.6	0,612	0,620	0,862	0,667	0,850	0,558
19	QA.7	0,789	0,770	0,886	0,768	0,730	0,646
20	QA.8	0,592	0,530	0,636	0,570	0,610	0,504
21	QA.9	0,437	0,630	0,681	0,654	0,791	0,387
22	QA.10	0,589	0,671	0,704	0,675	0,675	0,479
23	QC.1	0,575	0,644	0,666	0,811	0,668	0,780
24	QC.2	0,478	0,604	0,697	0,786	0,706	0,790
25	QC.3	0,484	0,670	0,610	0,776	0,649	0,572
26	QC.4	0,422	0,518	0,624	0,691	0,575	0,693
27	QC.5	0,572	0,624	0,545	0,744	0,584	0,638
28	QC.6	0,579	0,692	0,668	0,857	0,737	0,587
29	QC.7	0,625	0,734	0,844	0,862	0,777	0,617
30	QC.8	0,654	0,769	0,641	0,642	0,595	0,332
31	QC.9	0,421	0,753	0,599	0,751	0,622	0,587
32	QC.10	0,681	0,781	0,777	0,813	0,718	0,627
33	QC.11	0,484	0,668	0,652	0,784	0,774	0,509
34	QC.12	0,639	0,610	0,675	0,661	0,652	0,484
35	QC.13	0,476	0,485	0,539	0,649	0,579	0,395
36	QC.14	0,673	0,742	0,630	0,780	0,709	0,560
37	QC.15	0,669	0,479	0,667	0,665	0,560	0,650

Table 4 Discriminant Validity Value (Cross Loading)
(continued)

No	Indicators	Lean - Waste (X1)	Quality Planning - PQM (X2)	Quality Assurance - PQM (X3)	Quality Control - PQM (X4)	Quality Improvement - PQM (X5)	Track Quality (Y)
38	QI.1	0,345	0,560	0,541	0,652	0,683	0,384
39	QI.2	0,582	0,603	0,597	0,704	0,775	0,478
40	QI.4	0,595	0,412	0,447	0,447	0,606	0,258
41	QI.5	0,729	0,716	0,738	0,776	0,772	0,579
42	QI.6	0,489	0,686	0,504	0,563	0,623	0,316
43	QI.7	0,631	0,450	0,588	0,544	0,632	0,572
44	QI.9	0,449	0,744	0,684	0,747	0,722	0,497
45	QI.10	0,448	0,683	0,757	0,733	0,802	0,430
46	QI.11	0,484	0,665	0,639	0,634	0,857	0,524
47	QI.12	0,455	0,597	0,633	0,604	0,814	0,562
48	QI.13	0,434	0,565	0,705	0,660	0,817	0,478
49	TQ.1	0,518	0,451	0,460	0,609	0,469	0,725
50	TQ.2	0,517	0,527	0,546	0,678	0,521	0,808
51	TQ.3	0,530	0,421	0,455	0,577	0,441	0,604
52	TQ.4	0,607	0,555	0,690	0,788	0,644	0,801
53	TQ.5	0,508	0,516	0,485	0,446	0,334	0,743
54	TQ.6	0,543	0,537	0,601	0,609	0,516	0,855
55	TQ.7	0,478	0,441	0,457	0,556	0,446	0,791
56	TQ.9	0,483	0,364	0,408	0,455	0,410	0,637

Note: LN= Lean, QP= Quality Planning, QA= Quality Assurance, QC= Quality Control,
QI= Quality Improvement, and TQ= Track Quality.
(Source: SmartPLS Results)