ASTONJADRO

pISSN 2302-4240
eISSN 2655-2086

Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Application of the Six Sigma Method in Railway Level Crossing Construction using Concrete Level Crossing in Gedebage-Haurpugur, West Java

Verian Gustam Silvano, Darmawan Pontan, M. Zaki, Endah Kurniyaningrum

Program Studi Magister Teknik Sipil, Universitas Trisakti, Jakarta, INDONESIA

E-mail: veriangustam@gmail.com, darmawan@trisakti.ac.id, zakiachmad@gmail.com, kurniyaningrum@trisakti.ac.id

| Submitted: July 03, 2024 | Revised: July 07, 2024 | Accepted: December 28, 2024 |

| Published: January 03, 2025 |

ABSTRACT

The public interest in trains makes train traffic increasingly dense, resulting in congestion at railroad and highway intersections. Intersections between railways and highways are divided into level and non-level crossings. The potential impact or risk of the existence of a level crossing can cause several problems, one of which is the wheels of vehicles (motorbikes) which often slip when crossing the tracks. To reduce the potential risk of the existence of level crossings in the form of vehicle tires slipping between the rail gaps, PT. In 2022, KAI develop solutions to the problems that occur, one of the methods is by adding a concrete product in the form of Concrete Level Crossing, which is a prestressed concrete plate made with a knock down system so that it can be easily dismantled and assembled in the field without having to disrupt train travel schedules. This research was conducted to determine the most important factors in improving the quality of CLC plate construction at railway level crossings, to determine the application of the Six Sigma method to CLC plates at railway level crossings, and to determine the effect of applying the Six Sigma method to plates. CLC for railway crossings. The independent variable (X) in this research is the Six Sigma method, while the dependent variable (Y) in this research is the implementation of railroad crossing construction using Six Sigma-based Concrete Level Crossing (CLC). The questionnaire survey was carried out via an online survey. The number of respondents who provided assessments on this research questionnaire was 33 respondents from 5 related companies. The respondents taken in this research consisted of 4 experts with the expert criteria being personal experience in the field of planning and operational implementation in Concrete Level Crossing (CLC) installation work. The most important variable in improving the quality of CLC installations is the Quality Control variable. Only the Quality Control variable influences the implementation of Six Sigma in CLC installations. The results of the DPMO calculation show a defect value of 31,250 per million or the equivalent of 3.59 sigma, where the quality still needs to be improved to reach a value of 6 sigma.

Keywords: Concrete Level Crossing (CLC); six sigma; CLC installation.

INTRODUCTION

There are several types of transportation modes, namely land, sea and air transportation. In Indonesia, people still rely on land transportation to travel from one place to another. Land transportation is divided into road and rail transportation. Roads are transportation infrastructure that includes all parts of the road along with supporting buildings used for traffic, which can be above ground level, below ground level, or above water level. This does not include railway lines, truck-only roads, or cable roads (Republic of Indonesia Law Number 38 of 2004). Meanwhile, a railroad is a track for trains made of various materials such as concrete or steel, depending on the location and direction (UU. 23, 2007: 3). Transportation using rail often has the right schedule because there is no interference from other vehicles on the route.

Transportation that uses rail as its route is trains, MRT and LRT. Trains are rail land transportation that is quite popular with the public because they have a larger capacity compared to other rail transportation, and can serve longer distances.

The public's high interest in trains has increased the traffic density of train trips, which has also resulted in an increase in the density of intersections between railroads and highways. These intersections can be divided into level and non-level crossings. Level crossings occur when trains and highways intersect each other directly, where the geographic conditions of the railway line do not allow building a non-level crossing on it. Meanwhile, non-level crossings are intersections between railway lines and highways that are not on the same plane, such as flyovers or underpasses.

Figure 1. Level crossings in Bandung City Source: https://jabarprov.go.id/berita/pt-kai-imbau-pemudik-waspada-di-perlintasan-sebesar-8855

In large cities such as Jakarta, level crossings between commuter trains and national roads are avoided because they have a high risk of accidents, but in satellite cities or other small cities, especially on the island of Java, level crossings are still often encountered. Along with the number of level crossings which is still quite high on the island of Java, Asfiati et al. (2020) stated that PT. KAI (Persero) needs to improve aspects of safety, timeliness, ease of service and comfort in its operations. They also identified that level crossings have potential impacts or risks which include delays in train travel due to the need to reduce speed, slowing down the flow of vehicle traffic when passing through the crossing, disruption to the smooth flow of traffic which can cause queues of vehicles when the level crossing gate is closed, risk of wheel slippage. vehicles on rails, as well as damage to road pavement, especially at the meeting point between asphalt or concrete and railway tracks (Hisni I, 2022).

At level crossings there will of course be a gap between the train tracks and the rail ballast. In several areas on the island of Java, local residents usually fill these gaps themselves with wood or piles of gravel. However, in big cities, these gaps are usually cast using readymix concrete.

Of course, filling the gaps still cannot work optimally, because there are still many accidents caused by tires slipping into the rail gaps. To reduce the potential risk of the existence of level crossings in the form of vehicle tires slipping between the rail gaps, PT. In 2022, KAI will begin to develop new solutions to the problems that occur, one method is by adding a concrete product in the form of Concrete Level Crossing.

Concrete Level Crossing (CLC) is a prestressed concrete plate made with a knock down system so that it can be easily dismantled and assembled in the field without having to disrupt train travel schedules. In the CLC concrete there is rubber which is installed in the gap between the concrete and the train tracks, thus giving the train tracks space to expand and minimizing the surface of the concrete rubbing directly against the train wheels which causes quite large vibrations when the train passes.

Currently, one of the CLC concrete plates has been installed on the KM 166+500 Double Track Gedebage Segment, Haurpugur, Bandung, West Java. However, during the observation period after the product was installed, several defects were still found, one of which was that cracks appeared on the product after being passed by a train for several months. This will be analyzed further in this

pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

thesis using the Six Sigma method. Research Objectives and Uses, 1) to determine the most important factors in improving the construction quality of CLC plates for railway level crossings, 2) to determine the application of the Six Sigma method to CLC plates for railway level crossings, 3) to determine the effect from the application of Six Sigma on CLC plates to railway level crossings.

Rail tracks are the backbone of railway systems, providing the necessary infrastructure to guide and support trains as they traverse various terrains and regions. These tracks consist of two parallel steel rails that are fixed at a consistent gauge, or distance apart, to ensure the smooth and stable movement of trains. The path taken by rail tracks is meticulously planned to ensure efficiency, safety, and minimal environmental disruption, while also considering factors such as geography, urban development, and economic viability. The flow of railway lines begins with comprehensive planning and design. Engineers and planners analyze the landscape to determine the most feasible route for the tracks. This process involves detailed surveys and studies to identify potential obstacles such as rivers, mountains, and urban areas. Once the route is finalized, the construction phase begins, involving the laying of foundations and track beds. The track bed is crucial as it provides a stable surface for the rails, preventing deformation under the heavy load of passing trains. Ballast, a layer of crushed stone, is typically spread beneath and around the tracks to offer additional stability, drain water, and reduce vegetation growth (Tripradipta R et.al, 2024; Panjaitan H et.al, 2024).

As trains move along the tracks, the flow of rail traffic follows specific patterns dictated by the type of railway line, whether it is a high-speed corridor, a freight line, or a commuter rail system. Mainline tracks, which connect major cities and regions, often feature multiple tracks to accommodate higher volumes of traffic in both directions. Conversely, branch lines may consist of a single track with periodic passing loops to allow trains traveling in opposite directions to pass one another. Junctions and interchanges form critical nodes where different railway lines intersect, enabling trains to switch from one track to another seamlessly. Rail tracks are designed to follow the natural contours of the land, but significant engineering efforts are required to manage elevation changes and sharp curves. In mountainous areas, tunnels and viaducts are often constructed to maintain a relatively straight and level path. In flatter regions, long stretches of uninterrupted track allow for higher speeds and smoother operations. The alignment of rail tracks must strike a balance between minimizing travel distance and avoiding sharp turns or steep gradients, as these can limit train speeds and increase wear and tear on both the tracks and the rolling stock (Sugesti BG et.al, 2024; Rahmawati A et.al, 2024).

Gedebage Station Traffic

Gedebage Station (GDB) is a class I station for freight trains located in Cisaranten Kidul, Gedebage, Bandung, with an altitude of +672 meters above sea level. This station is included in the Bandung Operation Area II and is the easternmost station in the city of Bandung. Currently, this station is specifically focused on loading and unloading containers or containers so it is rarely used for the arrival and departure of passengers. Gedebage Station also functions as a place for crossing and overtaking trains, especially for trains coming from the east of Bandung.

Table 1. Data on trains passing through Gedebage Station

No	KA Name	Relation
1	Bandung Raya Ekonomi	CCL - KAC
2	Serayu	PSE - KYA
3	Turangga	SGU - GMR
4	Cibatuan	CB - PDL
5	Kahuripan	BL - KAC
6	Lodaya	BD - SLO
7	Malabar	ML - PSE
8	Galunggung	KAC - TSM

No	KA Name	Relation
9	Mutiara Selatan	SGU - GMR
10	Argo Wilis	GMR - SGU
11	Pasundan	KAC - SGU
12	Parcel Selatan	SB - BD
13	Pangandaran	GMR - BJR
14	Kutojaya Selatan	KTA - KAC

Source: ANDALALIN A Gedebage Station data for 2022

Based on the table listing the names of passing trains above, we can determine the operating speed of each type of passing train, namely as follows:

Table 2. Operating Speed of Each Type of Train

No	KA Name	Peak Passing Speed
1	KA Ekonomi	90 km/hours
2	KA Eksekutif	90 km/hours
3	KA Barang	90 km/hours

Source: ANDALALIN A Gedebage Station data for 2022

Container train services at this station began when the Bandung Container Terminal began operating. The construction of the container terminal aims to increase the smooth delivery of goods and reduce the number of container trucks plying the highway. (Source: Results of traffic impact analysis at Gedebage station, 2022)

The construction and development of activity centers has a direct impact on traffic movements on the road network system around the activity center. Currently, Gedebage Station has four active lines on the north side with line 2 being a straight line and lines 3 and 4 for container/container loading and unloading services plus 3 Badug lines on the south side.

Based on the results of the Gedebage Station Andalalin Report in 2022, the capacity of the Gedebage Station KM 165+575 level intersection at 06.00 - 18.00 is 1533,316 pcu/hour. Then for the speed of motorized vehicles passing on the Jl. South Gedebage is 34 km/hour.

Types of Gap Fillers Between Rails at Railway Level Crossings

Wood

In several areas, level crossings with illegal railroad tracks are still found. One of them is as in the following picture

.

Figure 2. Illegal Railway Level Crossing Source: Personal Documentation

pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

This of course becomes an obstacle to local traffic and also threatens the safety and comfort of the community. In this picture, people can still be found using wood to fill the gaps between the rails to reduce the elevation difference between the rails and the ballast. However, this actually makes the situation worse by increasing the possibility of motor vehicle tires slipping between the new gaps between the wood used. Therefore, other solutions are needed to reduce the risk of this problem.

Asphalt

Asphalt is a brown to black material consisting mostly of carbon and hydrogen, which is obtained from heavy petroleum fractions because it is very viscous (Hadiwisastra, 2009). Asphalt is a sticky hydrocarbon material, black in color with a shiny resin sheen, resistant to water, and has a gel-like texture which makes the road surface strong and durable. Currently, some level crossings between train tracks and highways use asphalt to fill the space between the train tracks and the road. However, asphalt roads often experience waves or cracks due to the expansion of railroad tracks that occur when exposed to hot weather.

The asphalt itself binds directly to the train tracks, so it does not provide a cavity for the rails to expand. Another cause of asphalt between bumpy rail gaps is that heavy vehicles such as trains pass at high intensity. This will certainly disturb the comfort and safety of motorists going back and forth on that road.

Figure 3. Railway level crossing with asphalt Source: Personal documentation

One of the main factors that causes damage to asphalt at railway and highway crossings is when the asphalt surface directly adheres to the railway ballast layer without an adequate foundation. Train ballast is a layer of gravel that functions to distribute the train load to the ground. When a train passes over it, movement occurs between the ballast gravel which causes displacement. In this context, train ballast becomes the main foundation for the asphalt layer above it, which is the main cause of damage to asphalt (Ba'nuelas et al, 2005). Ideally, a layer of asphalt should be placed on top of soil pavement or a solid foundation to extend the life of the asphalt.

Concrete Level Crossing (CLC)

Concrete Level Crossing (CLC) is a modular concrete panel that functions to channel the load of road and rail traffic to the ground. is a concrete panel made with a knock down system, where the parts of the plate can be distributed and installed easily in the field without disturbing the travel schedule of trains that will pass. CLC has been used in 20 countries around the world such as Austria, Germany and Japan

Figure 4. Railway level crossing with CLC. Source: Personal Documentation

CLC Panel Installation

In use, CLC panels need the correct installation method to ensure the product can function optimally. The following is a method for installing CLC products based on the work method procedure for installing WIKA BETON level railroad crossing (CLC) components.

Installation of type A1 foundation

Before CLC products are placed between train tracks, it is necessary to ensure that the ground where the CLC is placed has a flat elevation so that the CLC can function optimally in distributing the load of passing vehicles to the ground.

.

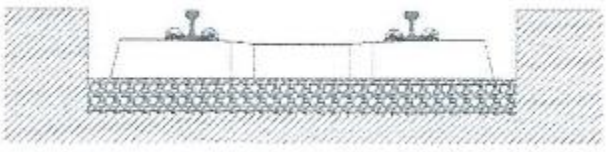


Figure 5. Laying CLC on Flat Land Source: Wika Beton Handling Manual

Dig the foundation soil to the plan level with a depth of around 40 cm according to the thickness of the product. Then, test the density of the ballast under the foundation using the CBR method. The CBR density requirement is a minimum of 8%. Compact the ballast using a stamper for a CBR of less than 8%.

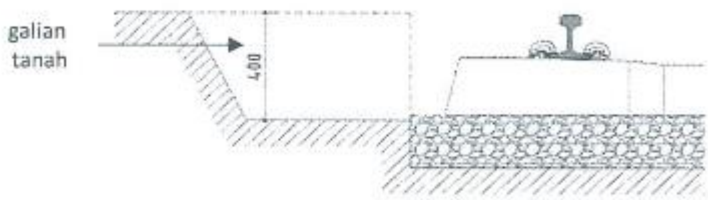


Figure 6. Excavation of foundation soil for CLC Source: Wika Beton Handling Manual

Place a tarpaulin on the surface of the excavated soil and temporary wooden supports between the side of the bearing and the foundation. The tarpaulin held by wooden shims functions so that the cement milk used to fill the gaps in the foundation does not seep out.

pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

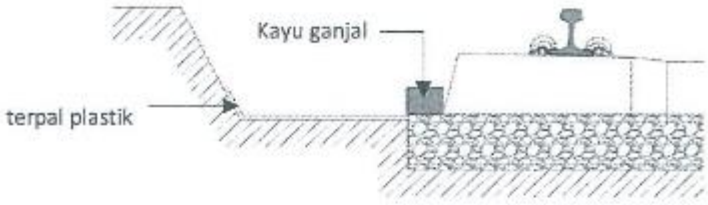


Figure 7. Installing Tarpaulin on Foundation Soil Source: Wika Beton Handling Manual

Place 2 5/7 wooden supports on the excavated ground to support the foundation. Each level between the wooden blocks is evenly spaced according to the plan using a spirit level and the distance between the wooden surface and the road surface is 35 cm.

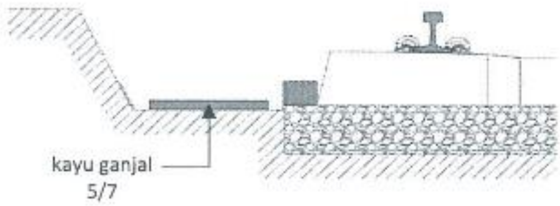


Figure 8. Installation of Wooden Wedges on Foundation Soil Source: Wika Beton Handling Manual

Lift the A1 foundation module using a 7 ton capacity crane truck. Place foundation A1 in the plan position. Make sure the surface of the foundation is level with the top surface of the rail by shimming where the bottom of the foundation meets with wooden shims

.

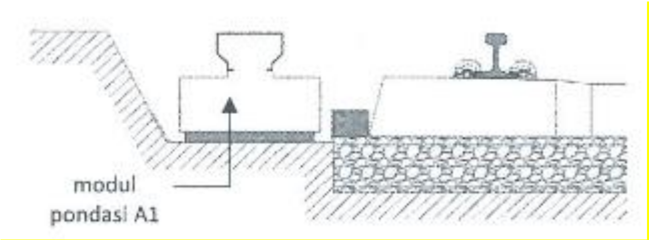


Figure 9. Installation of Modules on Foundation Soil Source: Wika Beton Handling Manual

Check the distance between the foundation and the rail with the installed mall that has been prepared. If it is not suitable, readjust the position of the foundation according to stage 1.

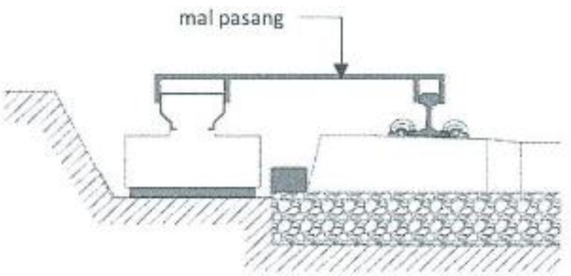


Figure 10. Mall Installation on the Module Source: Wika Beton Handling Manual

Stir the cement and water mixture with a w/c ratio of 0.4. Make sure the mixture is even. Adjust the volume to the need to fill the gaps at the bottom of the foundation.

Fill the gaps at the bottom of the foundation with cement milk using a grouting pump. Make sure all gaps are closed and there is no grouting material coming out of the plastic.

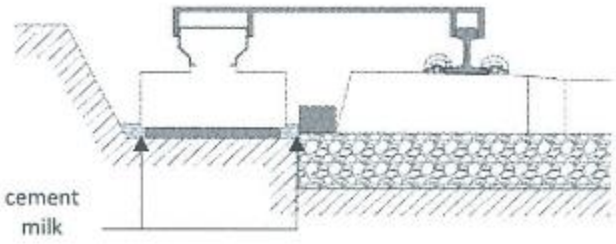


Figure 11. Filling gaps under the foundation with cement milk Source: Wika Beton Handling Manual

After the grouting has hardened (min. 1 hour), remove the temporary wooden supports, then fill and compact the gap at the back of the foundation and the part between the foundation and the sleeper using gravel.

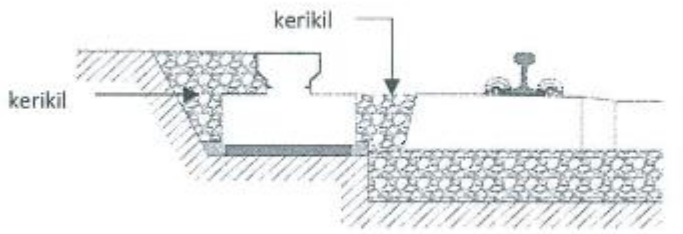


Figure 12. Filling Foundation Gaps with Gravel Source: Wika Beton Handling Manual

Installation of rubber strips and rubber rails

Install rubber rail R1 on Foundation A1 and rubber R2 and R3 on the rail. Make sure the rubber is installed in the specified position and installed properly.

Install the rubber strip on the A1 foundation and on the sleeper. Make sure the distance and position are according to plan.

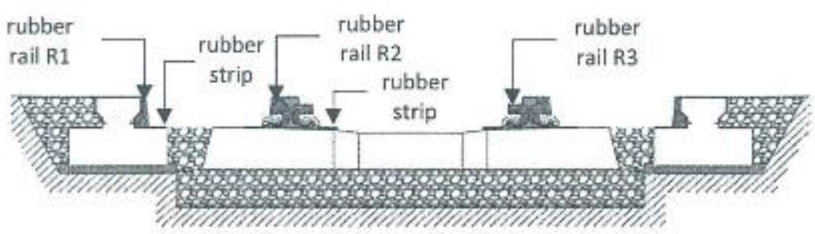


Figure 13. Installation of Rubber Strip on Foundation Source: Wika Beton Handling Manual

Installation of plate S1 in the middle and S2 in the left and right edges

Lift the S1 plate module using a 7 ton capacity truck crane. Place plate S1 in the plan position. Make sure the plate is installed properly in the planned position.

pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

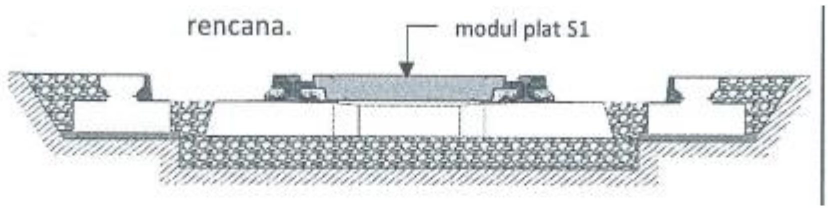


Figure 14. Installation of Plate in Planned Position Source: Wika Beton Handling Manual

Lift the S2 plate module using a 7tons capacity truck crane. Place plate S2 in the plan position. Make sure the plate is installed properly in the planned position.

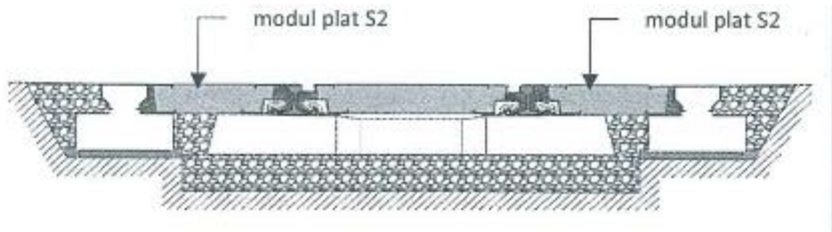


Figure 15. Installation of Plate 2 in the Planned Position Source: Wika Beton Handling Manual

Install stoppers at the ends of plastic S1 and plate S2

Dig out the ballast around the stopper seat

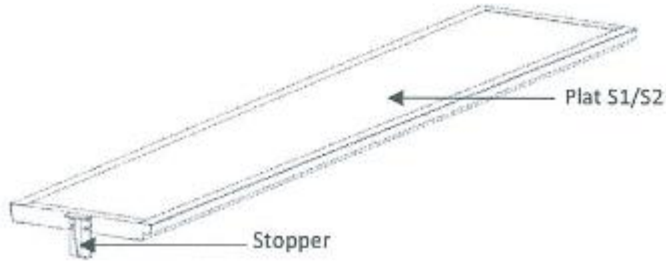


Figure 16. Excavating Ballast Around the Stopper Mount Source: Wika Beton Handling Manual

Install the stopper on the S1/S2 plate and tighten using M16 bolts

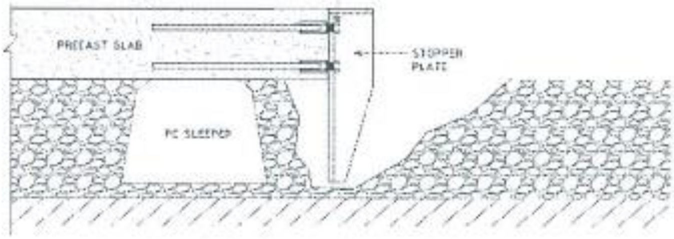


Figure 17. Installation of Stopper on Plate Source: Wika Beton Handling Manual

Backfill and compact the ballast

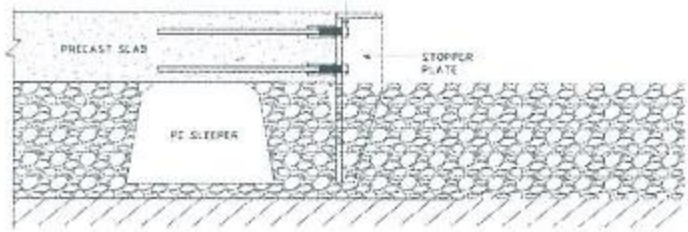


Figure 18. Backfilling and Ballast Compaction Source: Wika Beton Handling Manual

CLC Maintenance

Because it is designed with a knock down system, CLC products can be easily dismantled both during installation and maintenance. The following is a CLC product maintenance method based on WIKA BETON Concrete Level Crossing component maintenance procedures.

Dismantling of CLC plate components of type S1, S2 and A1 foundation.

Figure 19. Lifting and Stacking CLC Plate Source: Wika Beton Handling Manual

Move the rubber to a safe placement location. These rubber accessories will be reused when installing components after the track maintenance process

Basic Concepts of Six Sigma

Six sigma is a sustainable strategy to reduce waste, reduce variation, and prevent defects. This business concept aims to meet customer demands for the best quality and flawless business processes. Customer satisfaction is the main focus, and Six Sigma aims to eliminate uncertainty in achieving business goals (Smętkowska & Mrugalska, 2018). Six sigma refers to the distribution or spread (variation) of the average (mean) of a process or procedure, and is applied to reduce variation (sigma).

Six sigma uses Defects per million Opportunities (DPMO) as a quality measurement metric. DPMO is an effective indicator for assessing product or process quality because it is directly related to the number of defects, costs and wasted time. By using the ppm (parts per million) and sigma conversion tables provided in the attachment, the sigma level of a process can be determined. Based on existing techniques in manufacturing process improvement, Six Sigma principles can be used in construction operations according to the strategies described in research (Han, Chae, Im, & Ryu, 2008). As shown in Fig. 2.1, the concept of Six Sigma principles can be applied to construction process control within the basic framework of CTQ inputs, DMAIC procedures, and Output measures.

DMAIC as a Six Sigma Application

Six sigma is a comprehensive method for solving problems and improving processes through the DMAIC (Define, Measure, Analyze, Improve, Control) approach (Lestari et al, 2023). DMAIC is the core of Six Sigma analysis which ensures that the voice of the customer is integrated in the entire process to produce products that meet customer expectations (Gijo et al, 2011).

1. Define is the stage where the problem is clearly defined, customer requirements are determined, and Critical to Quality (CTQ) is identified.
2. Measure is the stage where the customer defect level (Y) is measured.
3. Analyze is the stage where the factors causing the problem or defect (X) are analyzed.
4. Improve is the stage where the process (X) is improved and the factors causing defects are eliminated.
5. Control is the stage where process performance (X) is continuously controlled to prevent defects from appearing.

SEM (Structural Equation Modelling)

pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

SEM or Structural Equation Modeling, is known by several other names such as covariance structure analysis, latent variable analysis, confirmatory factor analysis, and Linear Structural Relations (Lisrel) analysis (Mast et al. al, 2012). Conceptually, SEM combines factor analysis approaches, structural models, and path analysis. It can also be considered as a combination of regression analysis and factor analysis. Path Analysis and Confirmatory Factor Analysis are also special types of SEM because they focus on the relationship between dependent and independent variables

In SEM, there are three main activities carried out simultaneously: validation and reliability of instruments (confirmatory factor analysis), testing models of relationships between variables (path analysis), and developing structural models for predictions (structural models and regression analysis). An SEM model consists of two main components: a measurement model that evaluates validity and discriminant validity, and a structural model that describes the proposed relationships. To facilitate SEM data analysis, various statistical software such as Lisrel, AMOS, and Smart PLS are available.

Lisrel

LISREL (Linear Structural Relationships) is a software for implementing SEM that was developed by Karll Joreskog and Dag Sorbom in 1970. This software is used to process data with complex and complicated relationship patterns.

The advantage of LISREL is its ability to identify relationships between complex variables. This software has various operating options, both through syntax and a simpler program interface, making it suitable for use by various groups of users. The syntax may be preferred by users who have an understanding of programming languages. The disadvantage of lisrel software is its inability to process SEM data with a small number of samples. Small samples but with complex models will produce estimates that are not in accordance with planning.

AMOS

AMOS (Analysis of Moment Structure) is one of the software used to evaluate models in SEM. AMOS applies a general approach to analyzing data in structural equation models which includes covariance structure analysis or causal modeling.

The advantage of AMOS is that its use does not require complex syntax or programming languages. Users simply define latent and manifest variables, then connect them with the arrows provided. However, the weakness of AMOS lies in the number of complex images when the model becomes complicated. For more complex models, using a programming language such as that available in LISREL may be easier and simpler to operate.

Partial Least Squares (PLS)

PLS is a model in Structural Equation Modeling (SEM) that focuses on components or variants. In the SEM model, there are three main activities carried out simultaneously, namely instrument validation and reliability (confirmatory factor analysis), testing the relationship between variables (path analysis), and developing models suitable for prediction (structural model and regression analysis).

A complete modeling basically consists of two main components: a measurement model which is used to evaluate validity and discriminant validity, and a structural model or causal model which describes the hypothesized relationships. To make SEM data analysis easier, the use of various statistical software such as LISREL, AMOS, and Smart PLS is available (Yusandy A, 2013).

In this study, Smart PLS was used because it does not require various assumptions, the number of samples required for analysis is relatively smaller, it is easier to operate because it does not require a programming language, and the scale form can be tested in one model.

According to Marquez (2017), PLS is an alternative approach that is different from the SEM approach which is usually covariance-based, because PLS is variance-based. Variance, according to Marquez (2017), measures the deviation of data from the average (mean) value of a sample, which is a measure for metric variables. Mathematically, the variance is the average of the squared differences between each observation and the mean, so the variance represents the average value of the squared standard deviation. Every variable must have a variance that is always positive; if the variance is zero, it indicates that the variable is not a variable but a constant.

Measurement Model (Outer Model)

This research is reflective because the latent variable indicators influence the indicators, for this reason 3 methods of measurement are used according to Marquez (2017), namely:

1. Convergent Validity measures the magnitude of the correlation between the construct and the latent variable
2. Discriminant validity is carried out to ensure that each concept of each latent variable is different from other variables.
3. According to Haryono (2017), to determine Composite reliability, if the Composite reliability value is > 0.7 and Cronbach's alpha is above 0.60 then the construct is declared Reliable.

According to Marquez (2017) the statistical T value must be ≥ 1.96 and P Values ≤ 0.05 then the data is said to be valid.

Structural Model (Inner Model)

Inner Model (inner relations, structural model and substantive theory) describes the relationship between latent variables based on substantive theory. The structural model was evaluated using R-square for the dependent construct, Stone-Geisser Q-square test for predictive relevance and t test as well as the significance of the structural path parameter coefficients. The interpretation of the R2 value is the same as the interpretation of R2 of linear regression, namely the amount of variability of the endogenous variable that can be explained by the exogenous variable.

Path diagram (Path Diagram) PLS

Based on the research conceptual framework built on theory and concepts, an empirical model can be described.

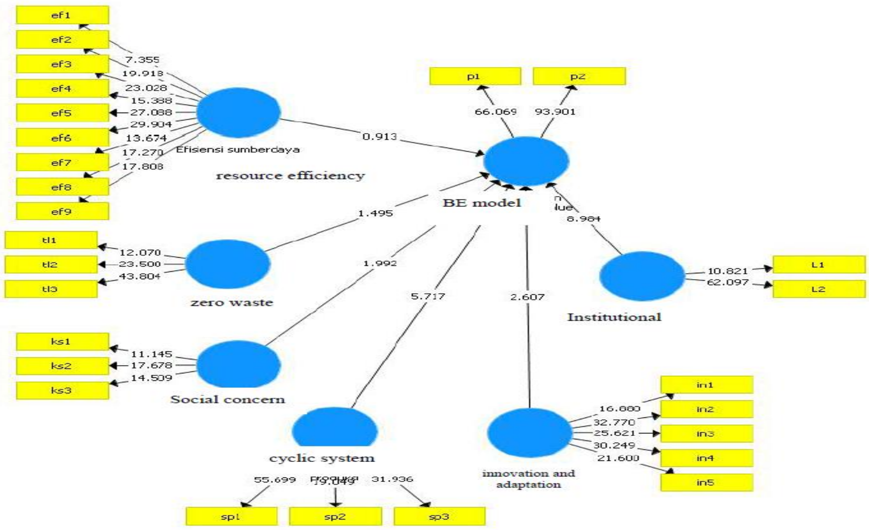


Figure 20. Example of PLS Path Diagram Construction Source: Rahmayana (2018)

Evaluation of Goodness of Fit

To validate the model as a whole, goodness of fit (GoF) is used. This GoF index is a single measure used to validate the combined performance of the measurement model (Outer Model) and structural model (Inner Model). The GoF index value is obtained from the averages communalities index multiplied by the R2 model.

RESEARCH METHODS

pISSN 2302-4240
eISSN 2655-2086

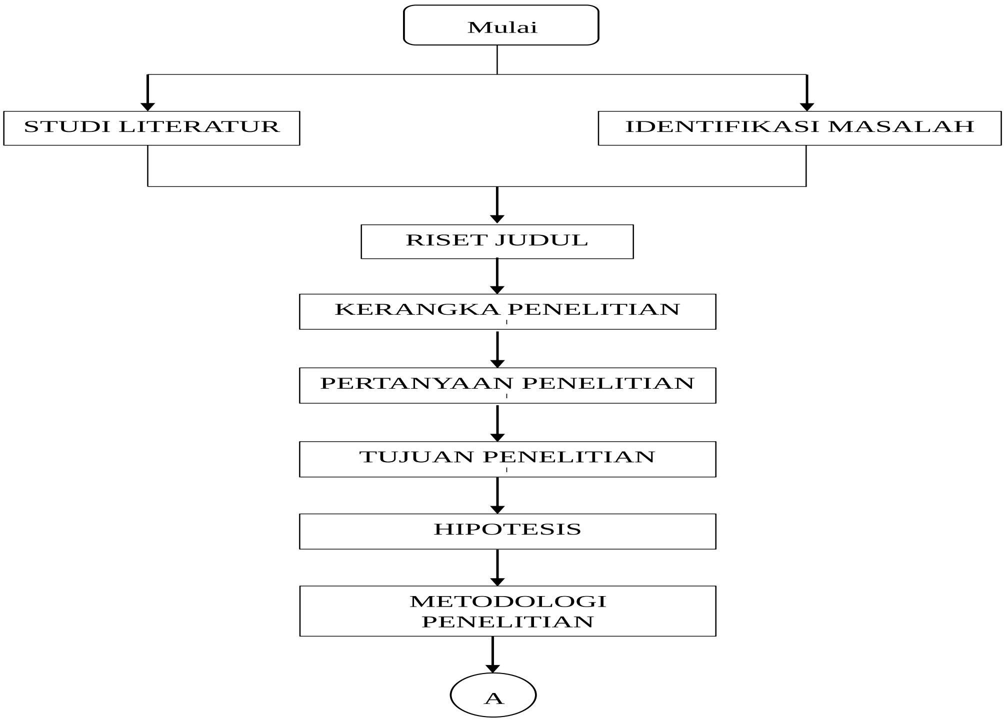
Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Research sites

The research was carried out at the Double Track railway crossing KM 166+500 Gedebage Segment, Haurpugur, Bandung, West Java. The reason for choosing the location for the Gedebage Segment, Haurpugur is because it is one of the experiments that PT KAI DAOP II has begun to launch using a new method, namely CLC, as an alternative to in situ concrete.

Research Flow

Research methods can be interpreted as procedures or scientific steps used to obtain data to fulfill research objectives. The investigation carried out is based on logical considerations and objective factual data.



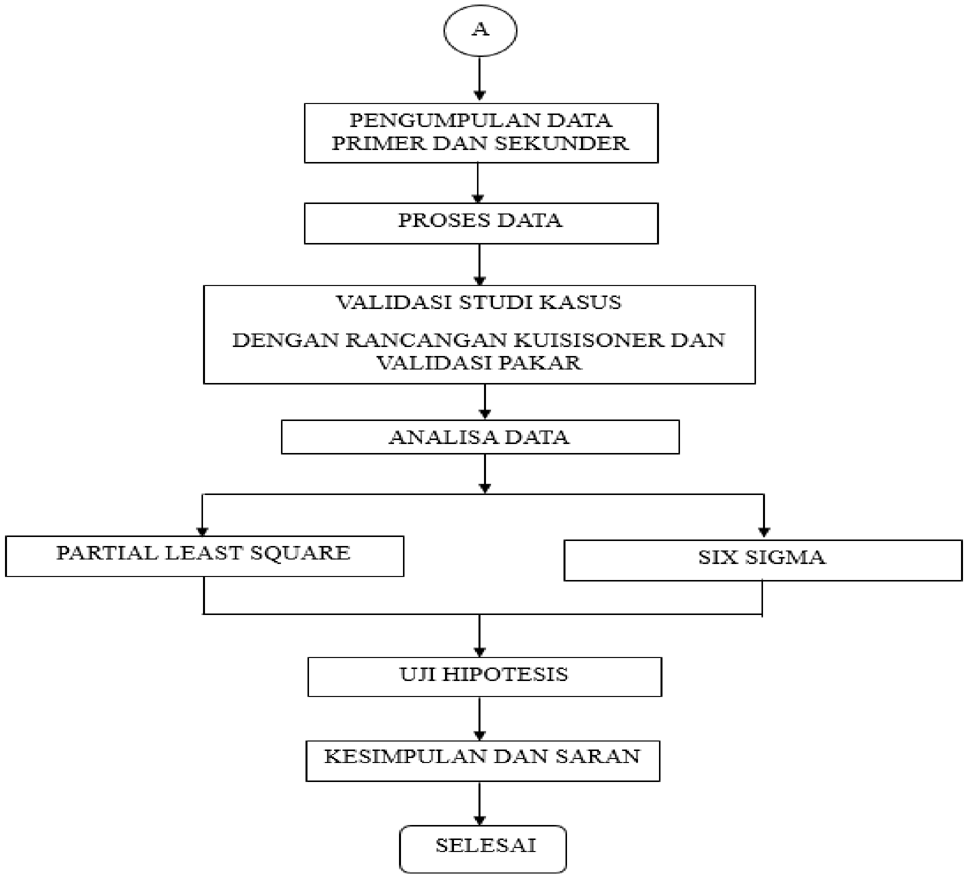


Figure 22. Research Flow for Research Implementation Stage Source: Personal Processing, 2024

Designing a Measurement Model (Outer Model)

Three measurement methods were used to design the measurement model (Haryono, 2017), namely:

1. Convergent Validity measures the magnitude of the correlation between the construct and the latent variable. In evaluating Convergent Validity from examining individual item reliability, it can be seen from the standardized loading factor. Standardize loading factor describes the magnitude of the correlation between each measurement item (indicator) and its construct. Correlation can be said to be valid if it has a value > 0.5.
2. Discriminant validity is carried out to verify that each concept of the latent variable is different from other variables in the model. Discriminant validity is considered good if the loading value of each indicator of a particular latent variable has a higher loading value compared to the loading value of other latent variables.
3. To determine Composite reliability, if the Composite reliability value is > 0.7 and Cronbach's alpha is above 0.60 then the construct is declared Reliable.

Designing a Measurement Model (Inner Model)

The Inner Model (inner relations, structural model and substantive theory) illustrates the relationship between latent variables based on existing substantive theories. The structural model was evaluated using R-square for dependent constructs, Stone-Geisser Q-square test for predictive relevance, as well as t tests and significance of structural path parameter coefficients.

Apart from looking at the R-square value, the PLS model is also evaluated by considering square predictive relevance to assess how well the model can produce observed values and estimate relevant

pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

parameters. A Q-square value greater than 0 indicates that the model has good predictive relevance, while a Q-square value less than 0 indicates that the model has less predictive relevance.

Evaluation of Goodness of Fit

Goodness of Fit (GoF) is used to test the overall validity of the model. The GoF index is a single measure used to evaluate the combined performance of the measurement model (external model) and structural model (internal model). The GoF index value is calculated by multiplying the average communality index by the R-square model.

The top-line Com refers to the average similarity of the variables in the model, while the top-line R2 is the average of the model's R-squares. The GoF index has a value range between 0 and 1, where the interpretation is as follows: 0.1 (low GoF), 0.25 (medium GoF), and 0.36 (high GoF).

Six sigma Validation Method

The Six Sigma concept redefines the definition of quality performance as the rate of defects per million opportunities (defects per million opportunities). The application of DPMO allows us to define quality more broadly. Calculation of DPMO and sigma level for attribute data can be calculated by following the following steps, namely (Khaedir et al., 2010):

1. Unit (U) is the number of products checked in the inspection
2. Opportunities (OP) are critical characteristics for quality that have the potential to become defects.
3. Defect (D) is the number of defects that occur in the work item
4. Defects per Unit (DPU) is a measure that reflects the average number of defects, all types, to the total number of units of the units sampled.
5. Defects per Opportunities (DPO) shows the proportion of defects over the total number of opportunities in a group.
6. Defects per million Opportunities (DPMO)
7. Sigma Level
   After calculating the DPMO, the sigma level can also be calculated by converting the DPMO value using the Six Sigma conversion table. The greater the sigma value, the fewer defects will result from the work.

After obtaining the sigma value and converting it to the sigma table and DPMO, you can start identifying problems starting from:

DEFINE

Identify problems by making a checklist of problematic work. At this define stage, the SIPOC (Suppliers Input Process Output Customer) table is presented which contains ideas for improving work that experiences defects or defects.

MEASURE

At this stage an analysis will be carried out using the Six Sigma Method by looking for the defect value per million. After that, proceed with drawing conclusions after the results of defects per million.

ANALYZE

This analysis stage is to analyze the causes and consequences of defects in a job. The presentation in this analysis stage is to use a fishbone diagram for each defect to make it easier to understand.

IMPROVEMENT

This is the stage where the identification process applies solutions to correct and prevent problems in the process. This stage uses brainstorming techniques such as Six Hats or Random Word. In some construction projects, more complex analysis tools or tools such as DOE (Design of Experiments) are usually used. Which focuses on solutions that are clear and convincing.

CONTROL

This control stage is a stage of re-checking the evaluation in the application of Six Sigma to every job that experiences defects.

RESULTS AND DISCUSSION

Expert Validation

The respondents taken in this research consisted of 4 experts with the expert criteria being personal experience in the field of planning and operational implementation in Concrete Level Crossing (CLC) installation work. Expert profile to test indicators

Each expert will answer 58 indicators and 4 variables so that after carrying out validation testing the expert will get relevant and irrelevant indicators for CLC installation work to be analyzed at the next stage.

PLS Calculation Model

The relationship between variables and indicators in this research using Smart PLS 4.2 is depicted in Figure 4.1 Initial Model. In Figure 23, the initial model is the initial model before the elimination/modification of indicators is carried out

.

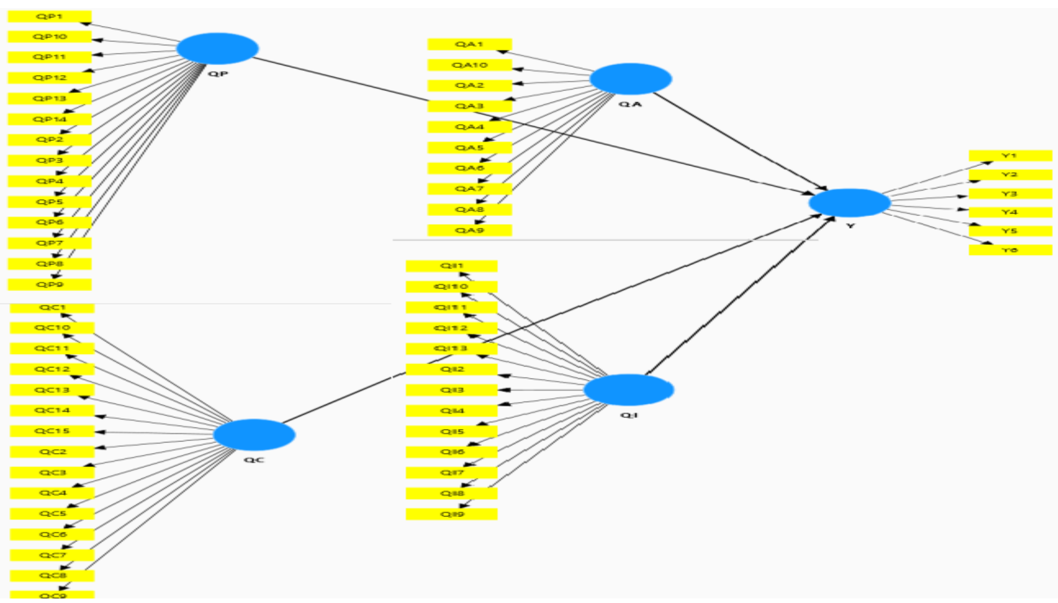


Figure 23. Initial Model Source: SmartPLS Processed Results

Measurement Model Testing (Outer Model)

There are three criteria for using data analysis techniques with SmartPLS to assess the Outer Model, namely Convergent Validity, Discriminant validity and Composite reliability.

Convergent Validity

Convergent validity of the measurement model with reflexive indicators is assessed based on the correlation between item scores or component scores estimated with PLS software.

Path Coefficient Output

Based on the path coefficient output in Figure 24 Convergent Validity, indicators that have a loading factor coefficient below 0.6 are dropped from the next research diagram.

.

pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

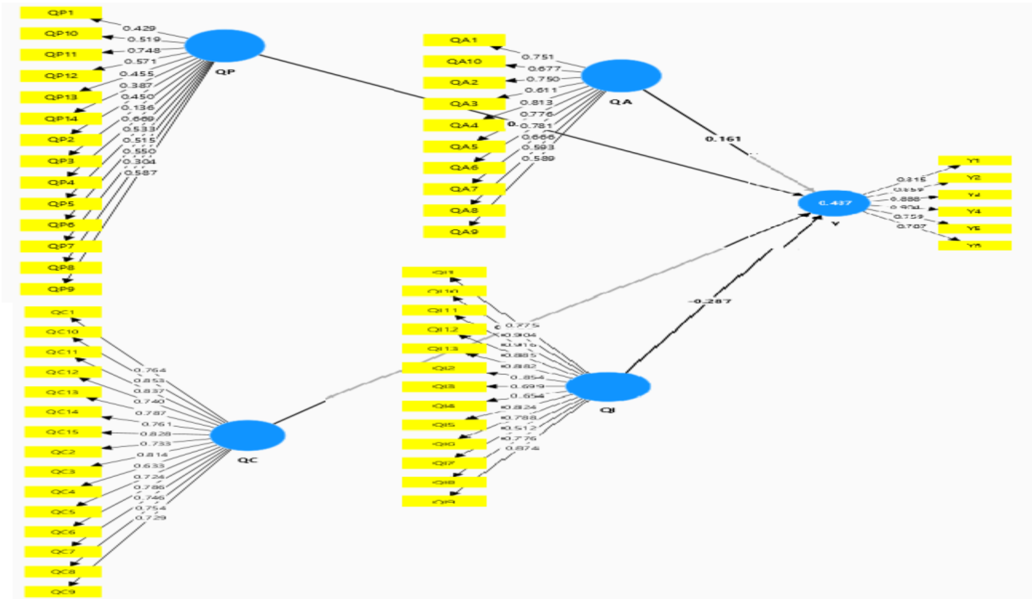


Figure 24. Source Path Coefficient Output: SmartPLS Processed Results

Fit Path Coefficient Output

After the indicators from the Path Coefficient Output diagram that have a loading factor coefficient below 0.6 are dropped, then the analysis is carried out again with PLS Software so that an indicator is produced that is above 0.6 in the results of the 3rd model analysis as shown in Figure 25.

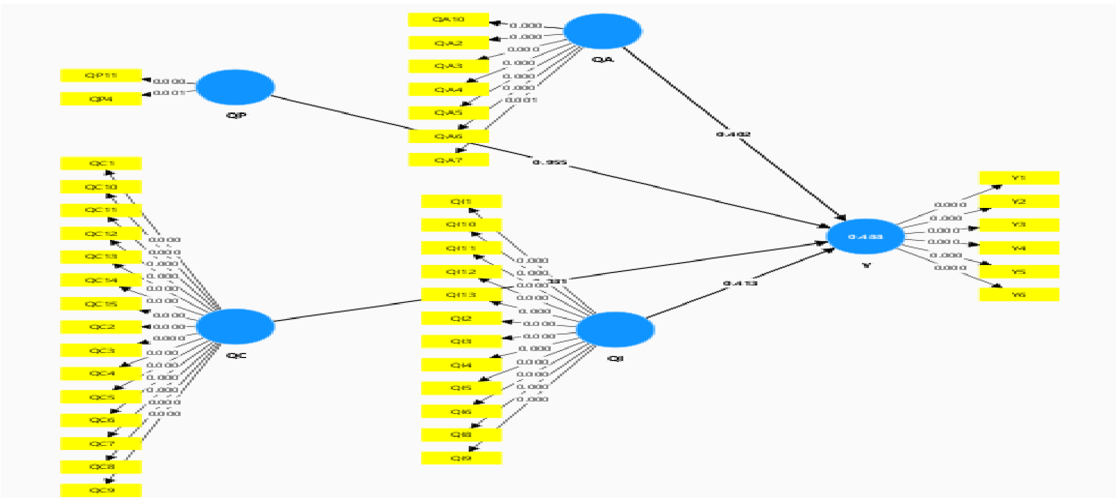


Figure 25. Fit Path Coefficient Output Source: SmartPLS Processed Results

Outer Loadings (Measurement Model) is the initial model of all indicator relationships with variables included in the calculation process. Modification is the elimination of values from the initial model whose initial model value is below 0.60, deleted/eliminated.

Convergent validity of the measurement model using reflective indicators is assessed based on the loading factor of the indicators that measure the variable. In this research, there are 4 variables with a total of 58 indicators on a scale of 1 to 6. Based on the path coefficient output above, indicators that have a loading factor coefficient below 0.6 are dropped from the next research diagram. The measurement model test results seen in the Convergent Validity figure Figure 25 and Table 4 Outer Loadings can be explained as follows:

1. The Quality Assurance variable is measured using Qa1 - Qa10. Of the 10 remaining indicators, 8 have a loading factor above 0.6.
2. Quality Control variables are measured using Qc1 - Qc15. Of the 15 indicators, all of them have a loading factor above 0.6.
3. Insurance variables are measured using Qi1 - Qi13. Of the 13 remaining indicators, 12 indicators have a loading factor above 0.6.
4. Planning variables are measured using Qp1 – Qp14. Of the 14 indicators, 2 indicators remain that have a loading factor above 0.6.

The loading factor results in table 5, indicators that have a loading factor below 0.6 will be dropped from the diagram and not included in subsequent calculations.

Discriminant validity

Discriminant validity is carried out to verify that each concept of the latent variable is different from other variables. A model is said to have good discriminant validity if each loading value of each indicator of a latent variable has the highest loading value with that latent variable than with other latent variables.

The value of cross loading also shows good discriminant validity because the correlation value of the indicator with the variable is higher than the correlation value of the indicator with other variables. As an illustration, the QA1 loading factor is 0.782 which is higher than the other loading factors, namely QC (0.633), QI (0.421), QP (0.371), and Y (0.512).

Composite reliability and validity

A variable is declared Reliable if it has a Composite reliability value above 0.70, AVE above 0.5 and Cronbach's alpha above 0.60. From the SMARTPLS output results above, all variables have Composite reliability values above 0.70, AVE above 0.5 and Cronbach's alpha above 0.60. So it can be concluded that this variable has good reliability.

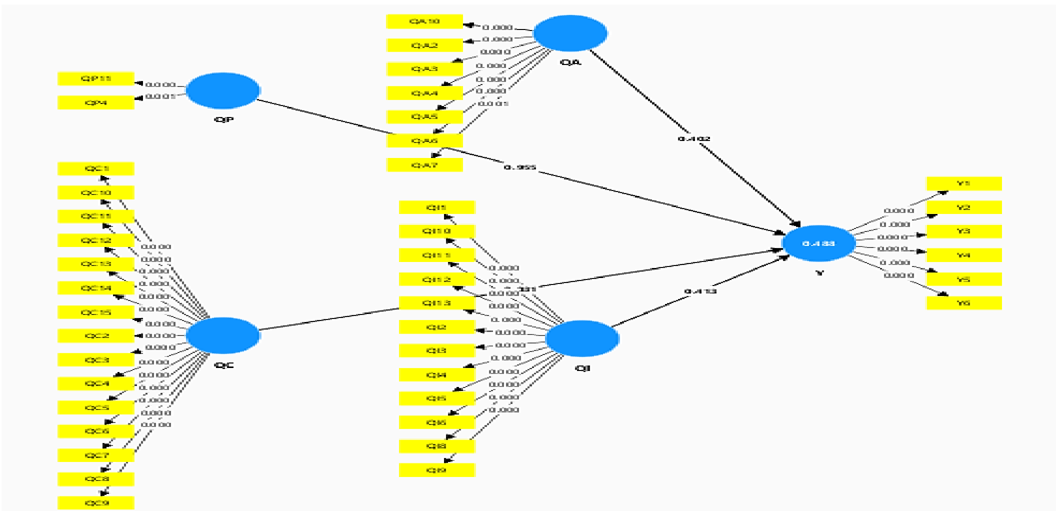


Figure 26. Final Model Source: SmartPLS Processed Results

This final model is the final model in which all indicators have been declared valid and reliable.

Measurement Model Testing (Inner Model)

The structural model in PLS is evaluated using R^2 for the dependent variable and the path coefficient value for the independent variable, whose significance is then assessed based on the T-statistic value of each path. To assess the significance of the prediction model in testing the structural model, it can be seen from the T-statistic value between the independent variable and the dependent variable in the Path Coefficient table in the SMART PLS Output as shown in table 4.

Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Variabel	Original Sample (O)	Sample Mean (M)	Standard Deviation (STDEV)	T statistics (|O/STDEV|)	P Values
QA → Y	0,161	0,115	0,336	0,479	0,632
QC → Y	0,758	0,611	0,365	2,078	0,038
QI → Y	-0,287	-0,22	0,315	0,914	0,361
QP → Y	0,033	0,254	0,225	0,145	0,885

Figure 27. Path Coefficients (Mean, STDEV, T-Value) Source: SmartPLS Processed Results

Application of Six Sigma

This research uses the Six Sigma method and will be integrated into the DMAIC (Define, Measure, Analyze, Improvement and Control) methodology. Six sigma is a business concept that seeks to answer customer demands for the best quality and flawless business processes.

Define

The define stage is the initial stage of the DMAIC cycle. At this stage, formulate what problems are currently occurring and determine which activities include value added and non-value added by creating a SIPOC table (Supplier, input, process, output and customer).

Table 4. CLC Installation SIPOC Table

Supplier	Input	Process	Output	Customer
Producer Concrete Level Crossing (CLC)	Material: - Rubber Strips - Rubber Rail - Wood Formwork	CLC Panel Production: - CLC Plate Setting - Reinforcement Setting - Installation of Accessories/Lifting Points - Product Opening Process - Product Finishing CLC Distribution Method	Concrete Level Crossing (CLC)	Indonesian people, especially the people of Gedebage, Bandung
	Plant: - Trailers - Forklift - Colt Diesel - Grouting Pump - Crane	CLC Panel Installation: - Installation of Type A1 Foundation - Installation of Rubber Strip & Rubber Rail - Installation of Middle, Left and Right Edge Plates - Installation of Stopper at the End of the Plate		
	Equipment: - Paint Markers - Trolley - Waterpass - Ink Pot - Chalk	CLC maintenance: - Dismantling of CLC Plate Components - Dismantling of CLC Foundation Components		

Source: Personal Processing, 2024

Measure

Measure is a process for evaluating the quality of the results of each job by identifying work results that are critical to quality (CTQ). To calculate the total defects in work and the total opportunities for defects to occur in each work inspection, the DPMO (Defect per Million Opportunities) method is used. Through a checklist carried out with the project owner, it was found that several work results did not meet the set quality targets.

Table 5. Summary Defect

No	Work Item	Location	Number of Defective Location Points	Information
Panel 1				
1	There are still subsidence at several points due to the existing load and unstable ground conditions		1	Closed
2	There is still horizontal movement, so there are gaps between segments	Path 1	1	Closed
3	There is a part of the Bend Plate that is torn		1	Closed
Panel 2				
1	There are still subsidence at several points due to the existing load and unstable ground conditions		1	Closed
2	There is still horizontal movement, so there are gaps between segments	Path 1	1	Closed
3	There is a part of the Bend Plate that is torn		1	Closed
Panel 3				
1	There are still subsidence at several points due to the existing load and unstable ground conditions		1	Closed
2	There is still horizontal movement, so there are gaps between segments	Path 2	1	Closed
3	There is a part of the Bend Plate that is torn		1	Closed
Panel 4				
1	There are still subsidence at several points due to the existing load and unstable ground conditions		1	Closed
2	There is still horizontal movement, so there are gaps between segments	Path 2	1	Closed
3	There is a part of the Bend Plate that is torn		1	Closed
		Total Defect	**12**	

Source: Personal Processing, 2024

Based on data from Table 4 and Table 4, the values obtained for finding DPMO with the Defect per Opportunities value for CLC installation work are:

Defects per Unit (DPU)

Defects per Unit (DPU) is a measure that reflects the average number of defects, all types, to the total number of units sampled. The DPU value is obtained by:

$$\mathrm{DPU} = \frac{\mathrm{D}}{\mathrm{U}}$$

With:
D = Defect = 12
U = Total Panel (Unit) = 4

ASTONJADRO
pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

Maka:
$\mathrm{DPU} = \frac{12}{4} = 3$ defect per panel
Defects per Opportunities (DPO)
Defects per Opportunities (DPO) shows the proportion of defects over the total number of opportunities in a group. The DPO value is obtained by:

$$\mathrm{DPO} = \frac{\mathrm{U}}{\mathrm{U\ x\ OP}}$$

With:
OP = Opportunities = 12

So:
$DPO = \frac{3}{(12\ x\ 4\ x\ 2)}$ = 0,03125 *defect* per opportunity
Defect per million Opportunities (DPMO)
The DPMO value is obtained by:

$$\mathrm{DPMO} = \mathrm{DPO\ x\ 1000000}$$

So:
DPMO=0.03125 x 1000000
DPMO = 31,250

Based on the sigma data shown in the table above for defects produced by installation work with a DPMO value of 31,250, it is equivalent to 3.59 sigma obtained from interpolation.

Based on the sigma value above, it can be concluded that the CLC construction at the railroad level crossing in Gedebage, Bandung has a defect value and the possibility of defects occurring in this work is quite high.

Analyze

This analysis stage is to analyze the causes and consequences of defects in a job. The presentation in this analysis stage is using diagrams

fishbone diagram for each defect.

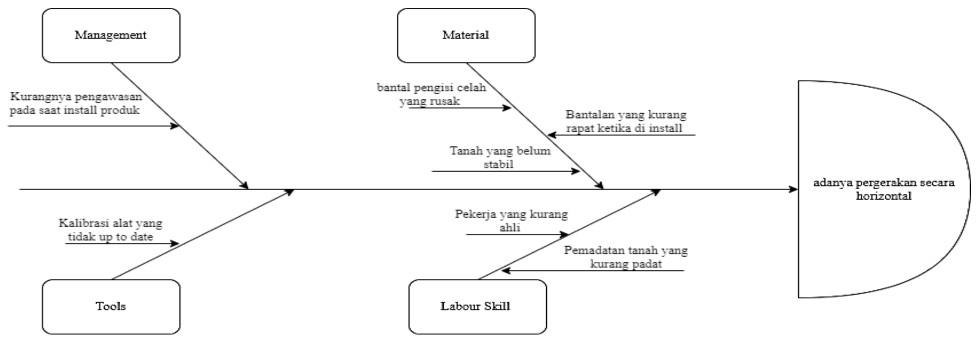


Figure 28. Fishbone Diagram of Work for Measuring Horizontal Movement Source: Personal Processing, 2024

In figure 28 is a fish bone diagram of the CLC installation work where horizontal movement was still found after the product was installed due to several factors, namely management problems caused by a lack of supervision when installing the product so that there was still a gap between the product and the ground. Then the problem with the tools used is that the tool calibration is not up to date. Apart from that, there is also a problem with the material caused by the pads filling the gaps between the rails being damaged so that the CLC position is not quite right.

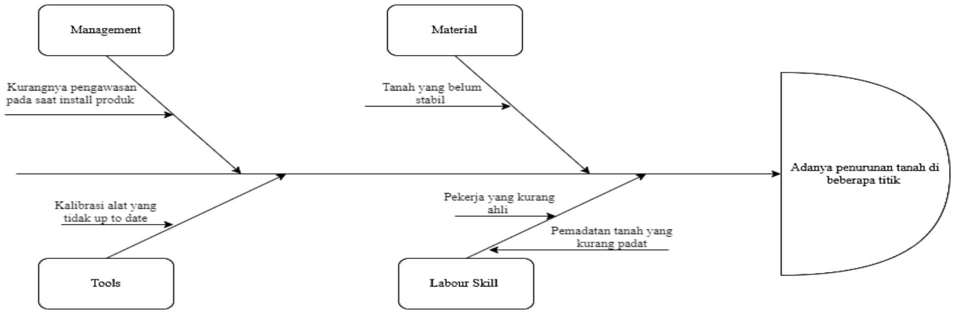


Figure 29. Fishbone Diagram of Work for Measuring Land Subsidence at Several Points Source: Personal Processing, 2024

Figure 29 is a fishbone diagram of the CLC installation work where land subsidence is still found at several points which causes the load received by the product to be uneven. This is caused by several factors, namely management problems caused by a lack of supervision during product installation so that workers tasked with compacting the soil do not meet the standards that have been set. Then the problem with the tools used is that the tool calibration is not up to date.

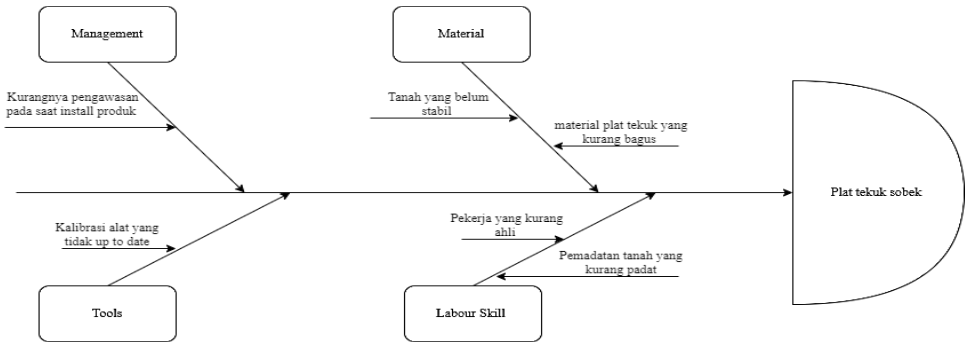


Figure 29. Fishbone diagram of measuring work for the presence of plate bending tears Source: Personal Processing, 2024

In figure 29 is a fishbone diagram of the CLC installation work where a torn bending plate item was found which caused the product to be unstable so that it moved horizontally too. This is caused by several factors, namely management problems caused by a lack of supervision during product installation so that workers tasked with installing the bending plate during the installation process do not place it correctly. Then the problem is that the bending plate material is not good enough so that it has defects after being installed at the location.

Improvements

Based on the results of questionnaire data processing, there is only 1 hypothesis that is accepted, namely hypothesis H2 "Quality Control has a positive influence on CLC installations". Hypothesis H2 is accepted so that the Quality Control variable is considered important in improving the quality of CLC installations. So the things that need to be done to improve the quality of CLC installations referring to Quality Control activities are as follows: Pre-Job Monitoring (before work starts):

pISSN 2302-4240
eISSN 2655-2086
Volume 14, Issue 1, February 2025, pp.0297-0320
DOI: http://dx.doi.org/10.32832/astonjadro.v14i1 http://ejournal.uika-bogor.ac.id/index.php/ASTONJADRO

1. Calibrate the measurement system (including all tools) that will be used in the work
2. Create tolerance standards during installation to maintain the installation process
3. Inspect the material/product to be installed before leaving the fleet and before being lifted to be installed in the rail gap.

Monitoring During Work (when work starts):

1. Implement each stage listed in the installation method that has been determined
2. Identify problems that have a high risk of occurring during installation
3. Inspect each activity in stages and make a report on the results of the work

Post-Job Monitoring (after work is done):

1. Compare work results reports between plans and actual installation in the field
2. Conduct a final inspection to ensure installation is carried out according to the method.
3. Define a valid and reliable system.

Control

The control stage is a phase to ensure whether the repair alternatives that have been prepared can be applied effectively and efficiently to reduce defects that occur during the installation process in the field. In this research, the method used to carry out the control process is to create a control sheet to monitor the installation contractor regarding things that should and should not be done during the installation process. Next, it is also necessary to carry out a resume process of several installation processes that have used the control sheet to find out whether the standards set in the control sheet are carried out regularly and according to procedures or not.

CONCLUSION

Based on the results of the analysis that has been carried out, the following conclusions can be drawn: 1) based on the results of the questionnaire survey and analyzed using SmartPLS, the most important variable in improving the quality of CLC installations is the Quality Control variable. Which consists of 15 factors/indicators which can be seen in the Improvement Sub-chapter. 2) it can be said that the only influence from the application of Six Sigma to CLC installations is the Quality Control variable. 3) The results of the DPMO calculation show a defect value of 31,250 per million or the equivalent of 3.59 sigma, where this value still needs to be improved in quality to reach a value of 6 sigma.

REFERENCES

Asfiati, et al. (2020). Studi Keselamatan dan Keamanan Transportasi di Perlintasan Sebidang Antara Jalan Rel dengan Jalan Umum. *Progress in Civil Engineering Journal*, Vol. 2. No. 1.

Aswad, Yusandy. (2013). Studi Kelayakan Perlintasan Sebidang antara Jalan Kereta Api dengan Jalan Raya . *Jurnal MKTS Vol 19, No. 2,* Universitas Sumatera Utara.

Ba˜nuelas, et al. (2005). A*n Application of Six sigma to Reduce Waste. Quality and Reliability Engineering International*, Glasgow Caledonian University.

Gijo, et al. (2011). *Application of Six sigma Methodology to Reduce Defects of a Grinding Process. Quality and Reliability Engineering International*.

Hadiwisastra, Sapri. (2009). Kondisi Aspal Alam dalam Cekungan Buton . *Jurnal Riset Geologi dan Pertambangan Jilid 19 No. 1*, Pusat Penelitian Geoteknologi LIPI.

Han, et al. (2008). *Six sigma-Based Approach to Improve Performance in Construction Operations*. *Journal of Management in Engineering*.

Insiyah, Hisni. (2022). Aspek Hukum Perlintasan Kereta Api Ilegal di Wilayah Warungbambu Karawang. *Jurnal Meta-Yuridis*, Vol. 5, No.1.

Lestari et al. (2023). Studi Keselamatan dan Keamanan Transportasi pada Perlinrasa Sebidang Rel Kereta Api dengan Jalan Raya (Studi Kasus Perlintasan Kereta Api Cimindi, Kota Cimahi) . *Majalah Ilmiah Teknik Sipil*, Universitas Negeri Semarang.

Márquez, et al. (2017). N*ew Methods for the Condition Monitoring of Level Crossings* . University of Birmingham.

Mast, et al. (2012). *An Analysis of The Six sigma DMAIC Method from The Perspective of Problem Solvin*g. *Int. J. Production Economics*, University of Amsterdam.

Undang-Undang Republik Indonesia Nomor 38 Tahun 2004, Undang-undang tentang Jalan, Jakarta.

Undang-Undang Republik Indonesia, Nomor 23 Tahun 2007, Tentang Perkeretaapian, Jakarta.

Manual Bantalan Jalan Rel. 2015. PT. Wika Karya Beton. Biro Teknik. Jakarta.

Tripradipta, R., Priyanto, S., Fahmi Amrozi, M. R., & Kemp, A. H. (2024). Analysis of Integrated Railway QR Code Mobile Payment Systems' Technology Acceptance. ASTONJADRO, 13(3), 708–721. https://doi.org/10.32832/astonjadro.v13i3.15571

Panjaitan, H., Priyanto, S., Dewanti, D., & Kemp, A. H. (2024). Internet of Things Implementation for Train Tracking Information (Case Study: UK and Indonesia). ASTONJADRO, 13(3), 732–746. https://doi.org/10.32832/astonjadro.v13i3.15646

Sugesti, B. G., Priyanto, S., Irawan, M. Z., & Whiteing, A. (2024). Encouraging the Shift of Modes of Freight Transport from Road to Railways in Indonesia (Case Study: Java Island). ASTONJADRO, 13(3), 779–790. https://doi.org/10.32832/astonjadro.v13i3.15684

Rahmawati, A., Dewanti, D., Parikesit, D., Timms, P., & Barnard, Y. (2024). Art and Transport: Background Music at The Train Stations in Java Island, Indonesia. ASTONJADRO, 13(3), 830–837. https://doi.org/10.32832/astonjadro.v13i3.15809