IMPROVEMENT OF THE LIGHTING SYSTEM DURING THE TRACK MAINTENANCE ON ADDIS ABABA LIGHT RAIL TRANSIT

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ABSTRACT
Track maintenance realized at the right time is critical for achieving efficient and optimized maintenance and renewal work plans, thereby increasing the life of track component; whereas work done later is unquestionably unsafe, and maintenance and renewal costs rise exponentially as the railway track gets older. The rising demand for train service necessitates large investments in track maintenance and repair. The railway system's efficiency is increased through cost savings and better maintenance management. Addis Ababa Light Rail Transit Service (AA-LRTS) conducts the track maintenance during the night due to the fact that the track is no longer in operation within this period. Different precautions are undertaken in order to protect the manpower but the lighting issue is no longer well considered during the track maintenance while this light is more necessary to light the workplace and to carry out some activities such as the verification of the inner rail performance. The review of different articles related to the key words mentioned within the study topic and the observation carried out during the track maintenance with the maintenance team of AA-LRTS are referred to achieve the goal of this study. The present study is going to highlight the robustness and weakness concluded from the methods adopted by AA-LRTS for track maintenance. Various suggestions are mentioned for the optimum safety required to achieve a reliable maintenance operation and manpower life improvement. By respecting the suggestions provided by the author, the maintenance team will develop the efficiency of the maintenance operation and the manpower life will be saved.

Keywords: track maintenance, track gauge inspection, track levelling inspection, safety, lighting system, AA-LRTS, Manpower life and maintenance performance.

1. INTRODUCTION

AA-LRTS provides different services including the maintenance service. The maintenance center is responsible for ensuring that all the equipment and facilities of the AA-LRTS infrastructure function properly and the operation goes smoothly. The maintenance service consists of the maintenance of track, rolling stocks, construction vehicles, signaling and communication equipment as well as ensuring normal operation of automation and network equipment. Each type of infrastructure is maintained as per the stream adopted by technicians. The present study is focusing on the track maintenance. The track maintenance method used by AA-LRTS is purely manual and the performance is low due to the human errors and imperfections. Two kinds of track maintenance are discussed within this paper such as gauge inspection and levelling inspection. The present study is emphasizing the case in which the two operations are conducted within the curve sections which are the critical points for track maintenance. Every maintenance operation starts by ensuring if the design measurements are still in normal range. Once the design measurements are not respected, the track requires the maintenance by making the actual measurements to the required ones for accurate operation of the track.

The issue concerning this document is observed for both above stated cases:

- The situation observed when adjusting the track gauge consists of lighting the workplace which is the problem for the manpower and for operation performance in terms of light insufficiency. It may cause wrong measurements and manpower injuries.
- The situation observed when adjusting the rail levelling consists of the light required to check the inner rail levelling as the simple visualization is the main method used for level checking. The light insufficiency may cause wrong measurements.

1.1. Background

1.1.1. Overview on AA-LRT structure

Addis Ababa Light Rail Transit (AA-LRT) is an urban rail transportation system in Addis Ababa that offers a service with sweet characteristics such as comfort, capacity, cost, safety, reliability, environmental friendliness, efficiency, attractiveness, accessibility, etc. The structure is divided into two lines (East-West and North-South) with a total of 39 passenger stations. The E-W line is stretching from Ayat to Torhailoch and covers the following features: 12.891km subgrade section, 3.91km elevated section, 0.197km underground section, 22 stations are available, the maximum station spacing is 1.26km, the minimum station spacing is 0.435km and the average station spacing is 0.798 km.

The N-S line is stretching from Menelik II Square to Kality Depot and covers the following features: 10.057 km subgrade section, 5.977km elevated section, 0.655km underground section, 22 stations are available, the maximum station spacing shall be 1.972km, the minimum station spacing shall be 0.435km and an average station spacing is estimated at 0.773km. Both lines have a 2.7km common track section from Stadium to St. Lideta. The AA-LRT was originally planned to have a total of 41 passenger stations on its two lines and each train was planned to have a capacity of 286 passengers. The minimum distance between stations is 435m while the longest is 2362m.This results in an average of 1398.5 m between passenger stations. The network has an underground section of 0.655km. It is a standard gauge rail (1.435mm) running trains at maximum operational speed of 70km/h. The gauge plane for AA-LRT is given as 16 mm while the standard value is 14 mm and the gauge is given 1445mm within the curve sections while the value adopted within the straight section is 1435mm which is the standard value. When the gauge is found less than the design gauge, it is called “Tight gauge” and when it is found greater, it is called “Slack Gauge”[1].

Figure 1: Addis Ababa Light Rail Transit Network

1.1.2. Overview on Railways track maintenance

Track maintenance and renewal work carried out at the right time is critical to achieve efficient and optimized maintenance and renewal work plans, thereby increasing the life of track components, whereas maintenance and renewal work carried out later is certainly unsafe, and as the railway track gets older, the maintenance and renewal costs increase exponentially. The railway track maintenance consists of repairing the defects which occurred in the railway alignment caused by the deformation of supporting materials such as ballast, sleepers and fastening systems. The horizontal alignment is repaired by adjusting the gauge whilst the vertical alignment is repaired by working out on the rail levelling state. Another case of railway track maintenance consists of replacing some parts of the components of the track that have been damaged. The present study focuses on the first case concerning the track alignment.

The failures related to the alignment are detected by simple measurement and visualization by checking if the design values are still within the convenient range. The track gauge measurement ruler is used to check the design gauge and the design superelevation. The versine approach is applied to verify the exactness of the inner rail within the curve section.

Once the measurement indicates that the values fall below the acceptable limit value, different techniques are conducted to reset the track to the initial state in order to provide efficiency in operation. The tamping process, ballast cleaning and dynamic track stabilization are famous applications for track maintenance as per the issue to carry out.

Tamping is one of the common methods applied to conduct the gauge and rail levelling inspection in order to reset track alignment. The tamping machine corrects geometrical alignment and compacts the ballast beneath the sleepers. This machine is capable of simultaneously altering the ballast position at speeds of up to 1.6 km/h, equivalent to 50 manual laborers in case of manual tamping[2].

The ballast cleaning is envisaged to deal with the ballast fouling that leads to track instability. Ballast cleaning is realized by using an automated equipment with an excavating chain that may be adjusted. The ballast is moved higher to the machine frame, where it is vibrated to remove dirt and other particles smaller than 35 mm. After that, the conveyor system returns the clean course materials to the ballast bed[3].

The dynamic track stabilizer is the machine used to rearrange the track after tamping. This rearrangement consists of the track lining and levelling, ballast consolidation, provision of an optimum homogenous settlement to the track. Thus, the dynamic track stabilization works out the compaction issue and ensure that track settles uniformly after the disruption due to the tamping process[4].

The famous method known as tamping process that uses the machine called tamping machine has been developed as the method used to repair track alignment by adjusting the gauge and rail levelling at once[2], [5]. It is really understandable that the method used by AA-LRTS is too far from that universal method because horizontal and vertical alignments are repaired by using different processes.

The gauge adjustment is carried out by pushing inside or outside the outer rail according to the results given by the measurements made on gauge distance verifications.

The rail levelling is proceeded basing on superelevation between the two running rails. For the straight section of the track, the superelevation is given as zero whilst in the curve section, this value depends upon the severity of the cant. The design-values are written onto the face of rails. For instance, some values of the superelevation have been observed during our sojourn on site such as 40mm, 60mm.

1.2. Statement of the problem

It is obvious that different services offered by AA-LRTS are still in need of improvement. The maintenance service is also included among those services in need of improvement. The method preferred by AA-LRTS for track maintenance has somehow the reasons even if it is not more effective. Some of them are the cost of the tamping machines mostly used by developed countries, the lack of sufficient power and enough space to introduce more needed facilities. The present document is drawn up to propose some alternatives that can be involved in order to solve this problem of lighting system during the track maintenances for AA-LRT in order to come up with the workers' safety and the performance of the maintenance operation.

1.3. Objectives

1.3.1. General objective

The general idea to come out within this study consists of the improvement of lighting system during the track maintenance on AA-LRT.

1.3.2. Specific objectives

This paper delineates different alternatives to be undertaken to ensure that manpower is working in safe condition especially in terms of lighting and ensure also if the light is enough for a well performed maintenance operation.

1.4. Significance of the study

AA-LRT is a newly rail metro constructed in Addis Ababa city. The performance of different services is still in need and different researches are conducted in order to improve the efficiency of different operations. The present study wishes to contribute in the improvement of the maintenance operation by proposing various ways to enhance the lighting system that helps the effective maintenance operation. By respecting the proposed recommendations within the present study, the manpower life will be sufficiently protected as the maintenance is practiced within the night and the maintenance operation will be effectively conducted due to truly results gathered during different measurements.

1.5. Scope and limitations

The handled paper is not going to describe in detail the methods of track maintenance. The main issue to overcome is the lighting system improvement to be undertaken for the method already adopted by AA-LRTS for track maintenance operation in case that the organization projects to maintain the method. Further suggestions are provided by the authors in case that the organization can be exposure to the change of the current maintenance method.

2.LITERATURE REVIEW

One of the important difficulties for railway operation, according to reports, is track maintenance, which necessitates accurate knowledge of rail status so that effective intervention may be undertaken only when necessary. The feasibility study of developing a fool proof diagnostic instrument to determine rail state using axle-box acceleration measurements for maintenance purposes has been explored[6]. The study demonstrated the ideal measuring points, as well as how the train's substructure and travel conditions influence the measured vibration levels.

One of the areas that stands out as particularly critical for ensuring a high level of safety and reliability of the infrastructure system is the maintenance operation. When the track condition goes below the acceptable limit value, immediate action should be undertaken to correct the problem and guarantee that the railway track fulfils all safety and quality requirements[7]. The corrosive effects of the surrounding environment, as well as the friction forces created by trains moving over them, pose a threat to the integrity of railway tracks[8], [9]. Due to this reason, railroad requires regular maintenance so that its usability can be more efficient. Three levels of maintenance have been carried and sorted as per the application time. These are the corrective maintenance, preventive maintenance and predictive maintenance. Corrective maintenance is performed only when there is a failure or malfunction, but preventive maintenance is performed when the equipment has maintenance plans in place to avoid/prevent the most complicated breakdowns. Whether or not preventive maintenance is required, it happens on the same timetable every cycle. Preventive maintenance is intended to keep things in good working order; however, it ignores the state of a component or process.

Predictive maintenance is performed as needed, based on real-time data collection and analysis of machine operation data, to discover concerns early on before they disrupt production. Repairs occur during machine operation and treat an actual problem with predictive maintenance. If a shutdown is necessary, it will be more targeted and shorter. For all those levels of maintenance, various operations are undertaken to come out with relevant results that help to increase the railway life span.

The involved methods within those sorts of maintenance are miscellaneous but, in some cases, none of these methods is sufficient and the complementarity can be involved. The factors such as investment, technologies, human resources/ability of operators, and collaborations with universities and research institutes have been mentioned as parameters influencing the selection of methods to adopt by the railway organizations to conduct the maintenance operation. Mostly railway organizations including Ethiopian Railways Corporation use traditional methods targeting corrective maintenance.

Researches show that the track maintenance can be split into two classes. The first class deals with the rectification of flaws in railway geometry induced by deformation of supporting materials like ballast and sleepers while the second class consists of correction of mechanical parameters that, in most circumstances, cannot be restored without the replacement of parts. The manual operations have been used since but up to now, all the activities are capable to be realized by using machine. The use of machine which is the option undertaken by the advanced countries in terms of technologies and finances is carried out for many purposes such as operation accuracy, minimizing the manpower which directly corresponds to the minimization of cost in terms of salary as well as the timing issue. A small group of people can maintain a reasonably lengthy stretch of railroad track thanks to modern machinery. The following activities are most realized during the track maintenance: the ballast tamping, track aligning, dynamic track stabilization, the ballast cleaning and ballast renewal, excavation and replacement of worn ballast, rail spiking, track components lubrication, rail grinding, bolts tightening, various components replacement.

Tamping is the most common method of ballast track maintenance, and it is also required for freshly constructed rail lines[10]. It also aids in the improvement of track stability and the performance of the ballast bed. In addition, by lifting and displacing the rail and sleeper, it corrects the ballasted railway geometry. In today's world, the tamping machine has largely replaced hand tamping in terms of speed, mechanization, and automation[2]. During the tamping technique, some undesirable outcomes may occur. Tamping's vibrations, for example, can cause a completely disrupted and loosening ballast bed. As a result of the disrupted ballast, lateral track instability occurs, putting the track in jeopardy. The infrastructure manager frequently executes the subsequent operations of re-compaction of the ballast after tamping, utilizing mechanical stabilization, to reduce this drawback.

The primary purpose of the dynamic track stabilizer is the improvement of the track geometry and stabilization of the surrounding ballast particles. Different studies highlight the principle of the dynamic track stabilizer[11]. During tamping process, the ballast under the sleepers is adjusted and cemented. The track is thus supported in its adjusted geometry by the ballast. There is an unconsolidated region because the tamping tools enter into the gap between the sleepers and are subsequently taken out after squeezing and consolidating. The ballast is not moved in front of the sleeper shoulders, but the train movement causes a gap at the sleeper ends. Thus, levelling, lining, and tamping processes restore the track geometry; but the ballast loses its stability and becomes inhomogeneous. The dynamic track stabilizer glides continually across the track after it has been tamped, causing the track to shake laterally. The track is loaded perpendicularly at the same moment. Because of the lateral vibration, the ballast rearranges itself without impact and fits together better. As a result, the entire ballast bed is homogenized and consolidated. The vertical stress, which can also change the level, increases the consolidation effect. The track becomes more stable after stabilization; the track geometry lasts longer, and the lateral stability or resistance to lateral track displacement improves. Furthermore, the loss of compaction of the ballast as a result of the vibration created during the tamping operation is a common cause of lateral track instability. The dynamic track stabilizer is used to alleviate this problem by compacting ballast more thickly and ensuring that the track settles uniformly.

Ballast disintegration, infiltration from the ballast surface, sleeper wear, infiltration from the underlying granular layers, and subsoil infiltration can all cause the ballast layer to become contaminated or fouled[12]. This will damage the ballast bed's bearing capacity and drainage function, resulting in a worsening of the ballast's function. Ballast cleaning becomes appropriate when there is more than 30% fine graded soil of less than 22.4 mm size in the ballast, according to European Rail Research Institute (ERRI), and it is absolutely necessary when there is more than 40%[7]. A ballast cleaner machine removes the fouled ballast and replaces it with cleaned and new ballast. Once the ballast is worn out or it is fouled by a material pumping from a local subgrade failure, the renewal option is envisaged in order to make the track in performed operation.

Railroad spikes are used to keep track gauge between the running rails and to fasten the steel rail to the railroad connection. Once they are damaged, the operation consisting to their change / fastening them to their appropriate connectors has to be executed so that the gauge can be maintained. This is the rail spiking.

The lubrication of various track components extends their life by decreasing wear and strain. The use of a lubricant to reduce friction and wear and tear in a contact between two surfaces is known as lubrication. For the rail lubrication, lubricants are applied to the side of the rails in railroad applications to prevent friction and wear that occurs between the flange part of the wheel and the gauge side of the rail on curved tracks[13]. Rail lubrication extends the life of the wheel and rail by reducing friction and wear at the rail-wheel interface, saves energy, and reduces wheel noise. It can also help to reduce lateral forces and flange climb forces, both of which can cause flange climb derailments.

For the Switch Expansion Joints (SEJ), the nuts and chairs can be removed during their maintenance. After cleaning the faces with a wire brush, a gap is formed between the tongue and the stock rail, and the interfaces are lubricated. After cleaning, the interfaces between chairs and tongue rails, as well as the interface between a chair and a stock rail, are lubricated. Tongue rails' stock is re-set. After replacing the chairs, the bolts and nuts are finally greased and tightened.

In case of the plate and rail screws, the plate/rail screws are removed from the track one by one. Screw and dowel are cleaned with a wire brush to remove any rusted material from the surface, then dipped in black oil uniformly on both the surface of the plate/rail screw and dowel, and then reinstalled. To prevent corrosion, the head of the plate/rail screw can be coated with hot bitumen or another suitable anticorrosive paint. The rail joint is lubricated to facilitate its expansion and retard the wear on the fishing planes of the rails and fish plate. It helps also to enable visual examination of rail ends for any crack/defects. Reduced wear on the fishing planes are one of the preventives of the low joints. Different substances are used such as Plumbago (Dry graphite powder), Kerosene oil (second quality) and the black or reclaimed oil which is only used for fish bolts and nuts.

Rail profile can present various faults due to the manufacturing process or as a result of the train operation activities. This kind of track imperfection is named rail corrugation, which is a periodic vertical irregularity on the railhead. Various problems caused by the corrugation have been highlighted. These are the increase in noise and in the vibrations experienced by passengers, ballast deterioration and higher maintenance cycles[14]. Rail grinding is a practical and cost-effective method for eliminating surface imperfections and maintaining good rail profiles[15]. Two modes of grinding have been mentioned such as preventive and corrective grinding. The preventive grinding prevents the development of defects growing from the surface or into the subsurface of the rail while the corrective grinding removes the defects on the surface after they have shown significant presence in the rail. In practice, the grinding machine is made up of a series of vehicles that have grinding wheels on them. The machinery grinds the rail surface as it runs along the track, re-profiles the rail, and then carries on. When it's utilized for grinding, many grinding units are blocked in one angle plane while the re-profiling operation is performed; the grinding wheels are adjusted at different angles to obtain a polygonal profile.

One of the most significant railway fasteners in the railway system is the railway bolt. Railway bolts are used to fasten rail track ends together at joints in general. They are also used to link the rails to the sleepers. The track operations may cause the weakness of those elements due to the vibrations provided by the trains. In order to make the smooth functioning of the track, the tightening system has to be carried out. To maintain the optimal torque and ensure a proper rail junction, track bolts must be tightened[16].

Bolt inspection and tightening should be viewed as a continuous and preventative track maintenance procedure. The frequency of inspection should be proportional to the amount of track usage. Tight bolts help to preserve accurate track gauge by contributing to tight rail joints. Track bolts that are properly tightened reduce unnecessary rail movement, which can lead to derailments and accelerate cross tie degradation at rail connections.

Furthermore, the replacement of the worn-out components has been involved as one of the methods to resort in case that the repairing issue cannot be much reliable. It is applied for all track components with disabilities to accomplish the convenient task. With advancements in technology, estimating the service life of a railway construction or a specific component has become much easier. The replacement strategy is then carried out based on a forecast of the track materials' economic life duration.

The execution of the above-mentioned operations requires a loud attention in order to protect the manpower against the injuries and make also a reliable performance. Since the maintenance service is still manual for AA-LRTS, safety of the manpower has to be taken into consideration. This issue involves many considerations which can cost too much for Ethiopian Railways Corporation.

Researches concerning the manpower safety during maintenance operation have been conducted. The protection in space and protection in time have been developed in Netherlands[17]. The methods have been involved for workers protection purpose because of the several accidents remarked while they were conducting maintenance operation. The protection in space consists of taking out of service the working zone when the track maintenance workers are working on it. And the protection in time consists of the maintenance scheduling of the working zone.

The safety management system for track maintenance workers has been developed by using a smartphone[18] in replacement of the previous method which used the radio through hand-signals and/or a radio. Using a basic Bluetooth module and safety jackets, the technology warns rail workers of train approaching information. In addition, the system enables a simple communication between the alarm system and smart phones by utilizing the Bluetooth capability of the smart phone. It has been determined that the strategy contributes to the prevention and reduction of railroad maintenance worker accidents by ensuring their safety and reducing railroad maintenance worker accidents.

Different measures have been introduced in order to improve the safety for the railway's users and workers. The referring study is the study conducted in Finland[18]. The study has shown that the introduction of central locking of doors in passenger vehicles and enhanced procedures to protect railway employees working on the rails are likely to have contributed to the increase in passenger and staff safety. Because of the installation of barriers and the construction of overpasses and underpasses at crossings with heavy traffic, the removal of level crossings and improvements in conditions such as visibility at crossings, the number of road users killed at level crossings has decreased. Specifically, to the railway employees, it has been concluded that the adoption of new norms and procedures to protect railway personnel working on the tracks, as well as a drop in the number of individuals working on the tracks since human labor has mainly been replaced by machinery, are possible causes for the decrease in employee fatalities.

According to the findings from the literature review, it is obvious that the method which is used by AA-LRTS is traditional and the stated problem has not been properly revised. This study will come out with some suggestions for the stated problem so that the AA-LRT can meet effectiveness in its maintenance operation. The track maintenance operators will also meet safety application once the highlighted suggestions are taken into consideration by the track managers.

3.METHODOLOGY

The methods used to come out with the stated issue is simply classified into two categories. The literature review about the track maintenance and safety issue as well as the Attentive Observation. The first category consists of collecting various ideas from relevant articles in respect of track maintenance while the second consists of the observation and the understanding of the knowledges shared with technicians of AA-LRTS during the maintenance operation. The time passed on site with the maintenance group of AA-LRTS has been an engine of thinking about the stated problem. The maintenance operation conducted in different locations such as the curve sections has pushed the author to wonder about the safety of the manpower and the maintenance performance issues due to the darkness noticed around the workplace. The devices used to improve the light furnished by the normal electric poles are only the torches. The workplace is elevated with a huge height. Hence, the light due to the electricity from the normal poles cannot even contribute to the required lighting. Recall that before any maintenance operation, the design measures have to be checked to ensure that those measures are breached or not and the decision to adjust the concerned section of the track can be stated. During this process of checking, technicians use torches for lighting and read gauge measurements on the apparatus. In this case, the problem pointed about lighting is no longer critical because the apparatus is well graduated and the values are visible.

The way the manpower moves over the track having various facilities made of steel and concrete without enough light is a big problem because it may cause injuries by hitting steel or concrete elements. Some kinds of holes are also observed along the workplace. Therefore, as the light is insufficient, people can fall down within those holes. During the maintenance operation, the same problems occur and the level of severity can increase. The manpower open and close the fastening system to adjust the gauge to the desired state. It is obvious that the manpower may make mistake by fixing the gauge to the wrong state.

During the fastening system manipulation, technicians can fall down in case that spanners and screws are no longer well connected. Concerning the maintenance operation conducted along the unelevated sections, lighting remains a critical issue in respect of manpower life and maintenance performance. Since this place is not elevated, the injuries for manpower can be taken at light level because the light from the normal electric poles contribute a little to the lighting of the workplace. But the performance of maintenance remains a challenge due to the manner utilized to check the levelling state of the reference rail. The simple visualization along a portion of rail to see if there is dip or bump is no efficient because the light from the torch does not have ability to identify clearly those irregularities. The way the manual compaction is conducted may lead to nervous effects onto the unconcerned track elements. As the light is not sufficient, the compactor can touch the rail and cause some wear which is the sad phenomenon for the rail life.

4. GAUGE ADJUSTMENT USED BY AA-LRTS

4.1. Tools

- String: used to apply the versine approach in order to fix the reference rail (inner rail);
- Gauge measurement device: used to check if the design measures are still within normal range;
- Spanner for fastening systems: used to weaken/fix the fastening system in order to easy the narrowing or widening of the gauge if necessary;
- Crow bar used to narrow or widen the gauge;

- Torches used to provide the light around the workplace.

4.2. Principle

The versine approach is used by AA-LRTS to ensure that the inner rail is laying in relevant conditions. The researches provide an algorithm design of Versine on railway line[19]. By supposing that the railway line starts with a straight line and ends with a straight line, the algorithm is described as follows:

1) Determine the kilometer mark using the tamping wagon's kilometer measurement system;

2)Get the starting coordinate value of the chord that takes L as a parameter by converting the kilometer mark to the arc length L;

3) Calculate the chord's ending coordinate value based on the chord line's length and current line type;

4) Calculate the chord line's midpoint coordinates based on the coordinate values of the beginning and terminating points;

5)To determine the normal's slope of the midpoint, calculate the chord's slope;

6) Determine the normal function that passes through the midway;

7)Using the normal function, calculate the normal and railway line intersection point coordinates;

8) To calculate the versine, use the distance formula between two places.

The versine-value adopted by AA-LRTS is 190mm. In case that this value is not attained or exceeded, the inner rail has to be arranged so that the gauge adjustment starts to be carried out. The inner rail will be pushed towards inside or outside according to the result given by the versine measurement.

The design gauge is taken as 1445mm for the curve sections whilst the standard gauge value is 1435mm. The track gauge is extended up to this value in order to easy the friction between the wheels and rails which occurs when the train is crossing within the curve sections.

Once the measurement shows that the gauge narrows about more than 3mm, that is, the design gauge is reduced of more than 3mm or once the measurement shows that the gauge widens about more than 9 mm, that is, the design gauge is increased about more than 9mm, the train cannot move along this section. Therefore, the gauge adjustment is required in order to make smooth track operation. Note that, during the track inspection, AA-LRTS has adopted that the gauge state is checked after 4 sleepers in case of the curve sections whilst it is checked after 6 sleepers for the straight section of the track. The following pictures demonstrate the way operators use the abovementioned tools and the applications of the versine approach during the track gauge adjustment.

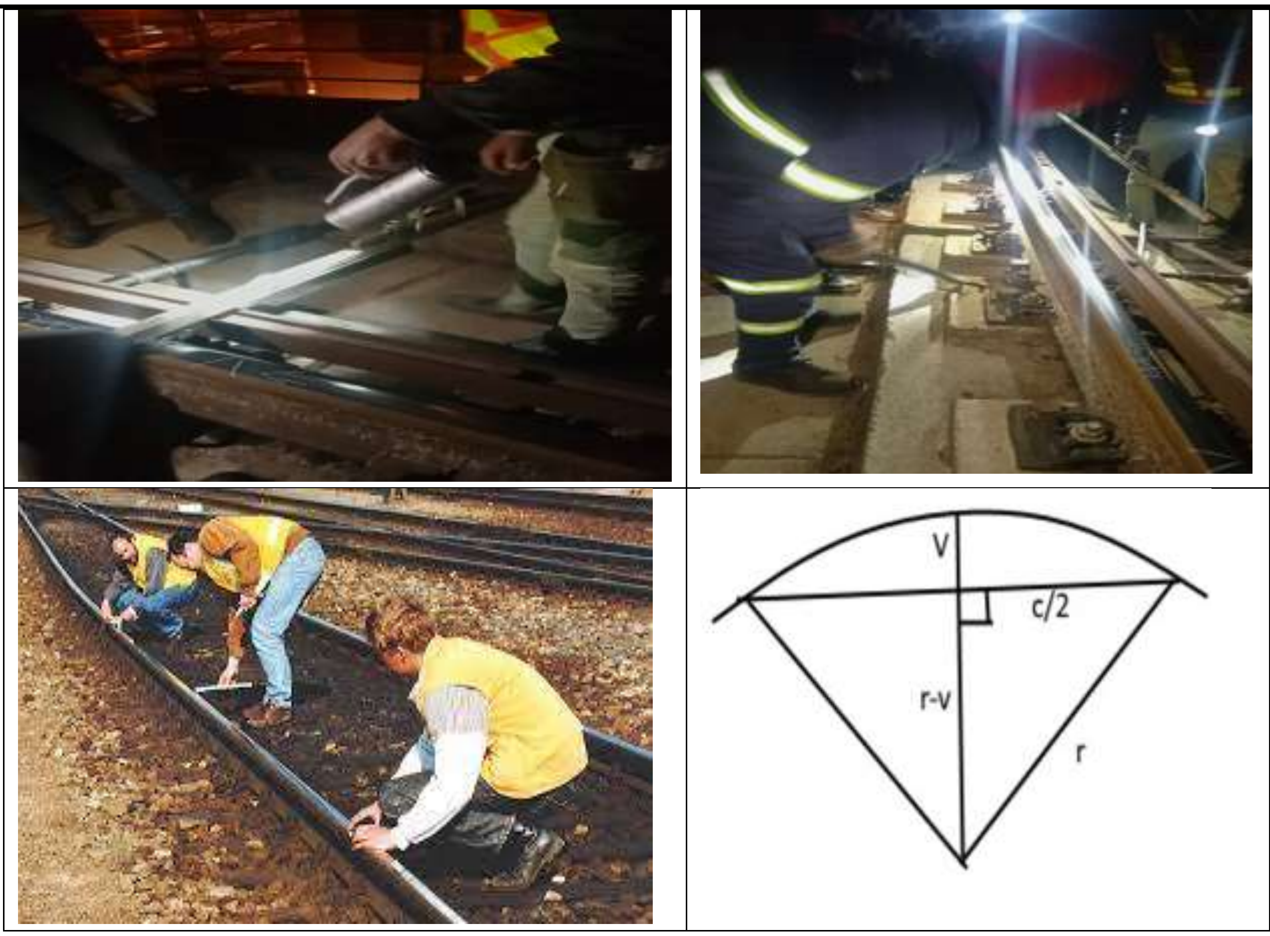

Figure 4.2-1 Illustrations of Gauge adjustment tools and principle

5. LEVELLING ADJUSTMENT USED BY AA-LRTS

5.1. Tools

- Ballast compacting machine
- Hydraulic Jack: used to shift the rail upward or downward as per the occurred situation
- Gauge measurement device: used to check if the design measures are still within normal range;
- Spanner for fastening systems: used to weaken/fix the fastening system in order to easy the narrowing or widening of the gauge if necessary;
- Crow bar used to narrow or widen the gauge;
- Torches used to provide the light around the workplace and verify visually the accuracy of the rail based onto its edge.

5.2. Principle

The rail levelling inspection adopted by AA-LRTS within the curve section of the track consists of checking the accuracy of the inner rail. The levelling state is verified visually. The technician illuminates the edge of the rail along a small distance and check by simple visualization if the rail has a dip or a bump. Once one of the two errors is remarked around a certain location of the rail, an attention leading to the adjustment has to be considered.

AA-LRT is designed with different superelevations as per the curvature degree. There is a tolerable extra value for the superelevation (4mm). When the superelevation, at a certain location, has an extra measure which is greater than 4 mm in both cases dip and bump, the rail levelling adjustment has to be carried out.

The rail levelling is conducted by inserting the hydraulic Jack under the rail location where the problem has been detected in order to push upward or downward the rail depending on the observed case. When the

Hydraulic Jack is inserted under the rail, the ballast compacting machine is used for compaction purpose in case of level reducing and stabilizing other track components such as sleepers and ballast densification. Once this operation is completed for a certain location, the maintenance operators move to another location and repeats the same process.

After having adjusted the referring rail, the operators turn back to adjust the outer rail by checking the gauge and levelling state. Note that the outer rail can also be arranged at the same time after the referring rail (inner rail) adjustment.

The following pictures demonstrate the way operators use the abovementioned tools during the rail levelling adjustment.

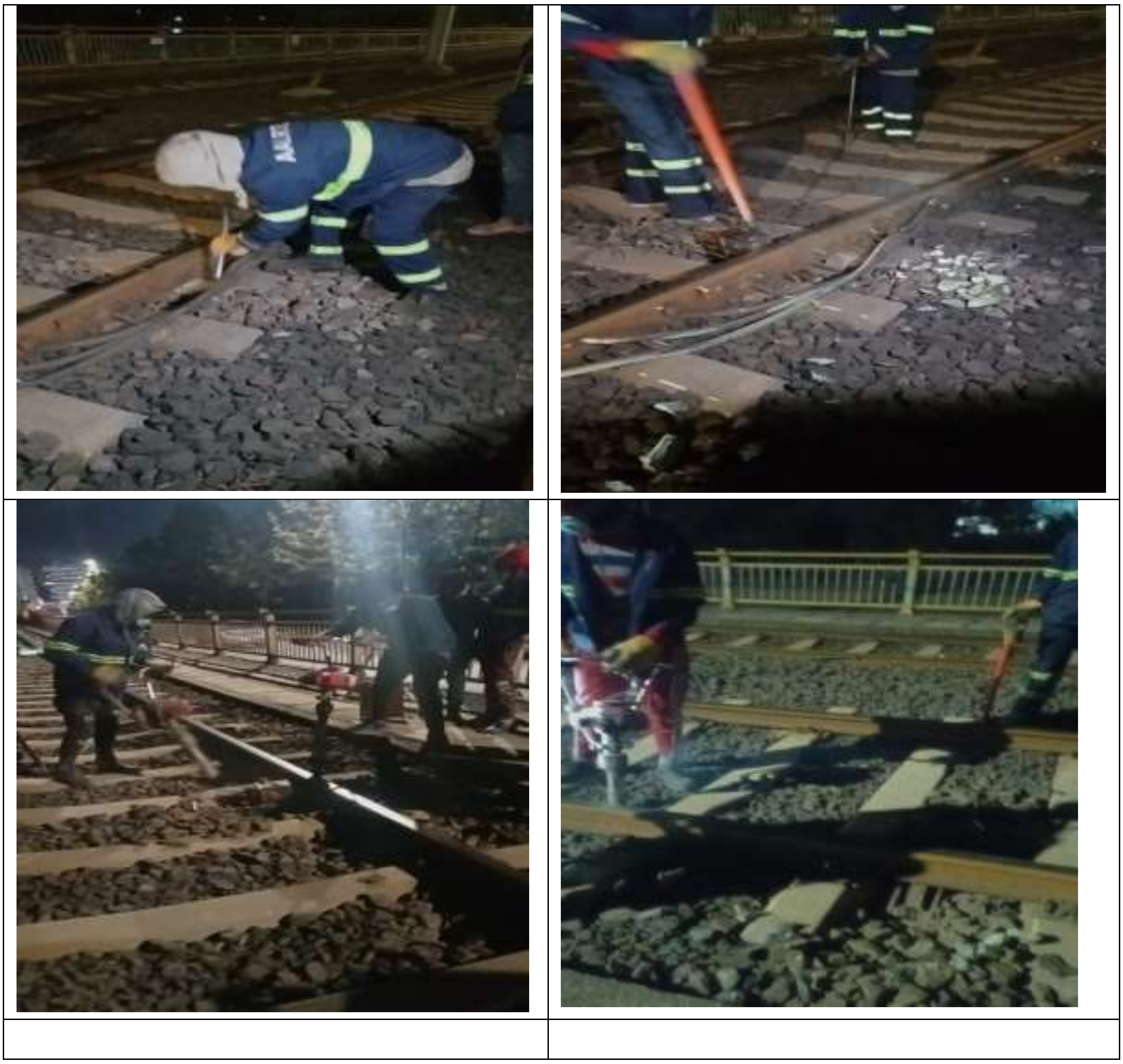

Figure 5.2-1 Illustration of Levelling Adjustment tools and principle

6. Conclusions

6.1. Findings

The observations carried on during the maintenance operation with the team of AA-LRTS in charge of track maintenance led to the following conclusions:

- The mode of track maintenance adopted by AA-LRTS does not have enough means to conduct accurately and economically the operation. Ethiopian Railway Corporation needs the introduction of different elements such as unmovable lightening facilities, advanced techniques such as mechanical tamping machine, experienced manpower;

- The schedule of maintenance operation is no longer respected;
- This mode of track maintenance involves a huge manpower but the productivity is no longer significant;
- The services provided by the manpower is not faithful due to the reason that manual and simple visualization services are rarely exact;
- The compaction made in the darkness and without appropriate control can easily lead to the ballast fouling which causes the light resistance of the track.
- This mode of compaction can also provoke the rail wear which harms the rail life.

6.2. Recommendations

Depending on the findings abovementioned, the tasks below are recommended to AA-LRTS in order to perform well for the maintenance operation and save the manpower life:

- Change the mode of track maintenance by using advanced techniques in order to reduce the manpower that can lead to failure of the company due to the enormous payment;
- In case that AA-LRTS prefers to maintain the use of the current method, it is recommended to install additional facilities along the track line that can provide enough light in order to reduce injuries that can occur to the manpower and improve the maintenance performance;
- Another mode of rail level checking for the referring rail is recommended in order to minimize the errors due to simple visualization. That is for instance the combination of camera platforms and computer vision techniques;
- It is better for the maintenance team to identify some locations with imperfections during the day time and mention them in order to minimize the difficulties of measuring during the night time.
- AA-LRTS has to address the idea to the company in charge of supplying the electricity in order to request the additional power and related facilities.

6.3. Areas for Further Work / Research

The study conducted has arisen more ideas that can lead to the future works for researchers. Apart the subject which led the above discussion, the ballast degradation due to the repetitive compaction can lead to the future research. Furthermore, the determination of the exact interval of maintenance operation can be another topic for the future research.

REFERENCES

1) M. S. Gauge, "TRACK GAUGE INSPECTION – Inspection Tips What is Track Gauge ? TRACK GAUGE INSPECTION – Measuring Devices Track Inspector ' s Tape Measure Spot-Check Laser Gauge," pp. 42–43.
2) Y. Guo, V. Markine, and G. Jing, "Review of ballast track tamping : Mechanism , challenges and solutions," *Constr. Build. Mater.*, vol. 300, p. 123940, 2021, doi: 10.1016/j.conbuildmat.2021.123940.
3) M. Sysyn, O. Nabochenko, V. Kovalchuk, and U. Gerber, "Evaluation of railway ballast layer consolidation after maintenance works," *Acta Polytech.*, vol. 59, no. 1, pp. 77–87, 2019, doi: 10.14311/AP.2019.59.0077.
4) B. Indraratna, W. Salim, and C. Rujikiatkamjorn, *Advanced Rail Geotechnology – Ballasted Track*. 2011.
5) G. Saussine, E. Azéma, R. Perales, and F. Radjaï, "Compaction of railway ballast during tamping process: A parametric study," *AIP Conf. Proc.*, vol. 1145, no. July 2009, pp. 469–472, 2009, doi: 10.1063/1.3179964.

6) M. Bocciolone, A. Caprioli, A. Cigada, and A. Collina, “A measurement system for quick rail inspection and effective track maintenance strategy,” *Mech. Syst. Signal Process.*, vol. 21, no. 3, pp. 1242–1254, 2007, doi: 10.1016/j.ymssp.2006.02.007.
7) E. C, *Modern railway track (second edition). MRT- Productions*. 2001.
8) C. E. C. Dg, “MAINTENANCE OF TRACK GAUGE Produced by Civil Engineering Conference For use by all railway civil engineering staff,” no. 1, 2001.
9) H. Guler, “Decision Support System for Railway Track Maintenance and Renewal Management,” no. June, pp. 292–306, 2013, doi: 10.1061/(ASCE)CP.1943-5487.0000221.
10) J. J. Kumara and K. Hayano, “Deformation characteristics of fresh and fouled ballasts subjected to tamping maintenance,” *Soils Found.*, vol. 56, no. 4, pp. 652–663, 2016, doi: 10.1016/j.sandf.2016.07.006.
11) K. Rießberger, “40 Years of ‘ Dynamic Track Stabilisation ,’” 1955.
12) E. T. Selig, “Track geotechnology.”
13) A. Alp, “Energy and wear analysis in lubricated sliding contact,” vol. 191, pp. 261–264, 1996.
14) S. Kumar, “LICENTIATE T H E S I S A Study of the Rail Degradation Process to Predict Rail Breaks A Study of the Rail Degradation Process,” 2006.
15) E. E. Magel and J. Kalousek, “The application of contact mechanics to rail profile design and rail grinding,” vol. 253, pp. 308–316, 2002.
16) “Value of Track Bolt Tightening Maintenance for Rail Users Track Construction & Maintenance,” 2019.
17) “The Netherlands Schedules Track Maintenance to Improve Track Workers ’ Safety,” vol. 37, no. 2, pp. 133–142, 2007, doi: 10.1287/inte.1060.0246.
18) J. Ku and D. Park, “Developing Safety Management Systems for Track Workers Using Smart Phone GPS,” vol. 6, no. 5, pp. 137–148, 2013.
19) Z. Bin Zhang, Q. Liu, H. R. Wang, and Y. Shen, “An algorithm for the curve versine measurements on railway tracks,” *Adv. Mater. Res.*, vol. 1030–1032, pp. 1955–1960, 2014, doi: 10.4028/www.scientific.net/AMR.1030-1032.1955.