NeTIRail

Needs Tailored Interoperable Railway Infrastructure

Deliverable D2.7

Lubrication systems and data available, with estimates of costs and benefits

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Lead contractor

INTADER

Contributors

USFD

UIC

SZ

Project Coordinator

University of Sheffield, USFD

Executive Summary

The research within this deliverable starts with a brief description of the importance of lubrication for railways. It is emphasized that to stay competitive with other transport modes, cost and capital investments should be reduced. Reducing wear will be paving the way of reducing costs.

The benefits of effective lubrication, lubrication effect including the effects of the elements of the systems, and the cost benefit of lubrication on railways will be described. The universal benefits of lubrication such reducing noise, wear, increasing asset life of rails and wheel, energy savings, reducing derailments are already known by IM and train operators, manufacturers… etc. In this report studies that have been carried out by infrastructure managers will be highlighted. Also, the cost benefits will be proven with the experiences of IMs.

As well as describing the existing lubrication systems, lubricators and lubricant, the systems under development will be analysed. To build a base for the next task of defining the tailored lubrication systems, the experiences of IMs in their countries will be examined. Best practices and bad practices will be highlighted. Also, on-board and on-track lubrication will be considered to reduce rail wear. Lubrication practice should be different for different lines/traffic density and weather conditions. therefore, the climatic information of the countries will be defined. This report will build a base for the next deliverable “Tailoring lubrication to duty and climate: Safe, effective and eco-friendly avoidance of track wear and damage”

As TCDD prefers not to nominate the companies that it collaborates or collaborated with, the experiments conducted by using different systems was separated into ANNEX-1. Also, the names of the lubricant companies that were nominated by TCDD was separated in ANNEX-1 too. For fine tuning of some text was rewritten. Also the annexes containing the results of the questionnaires have been excluded from this public deliverable.

The deliverable D2.7 relates to task T2.5.1 “Lubrication systems and data”. This task had the following aims or objectives which were achieved:

- Research and test the rail-wheel lubrication and appropriateness for different lines/traffic density of operations and weather conditions
- Consider on-board lubrications vs track side lubrication to reduce rail wear

Task description of T2.5.1 predicts that INTADER will lead the task based on the experience and needs for lubrication on their network. USFD have experience of the effect of lubrication on rail-wheel contact, especially wear rates of track and effect of reliability in lubricant application on fatigue life of rail steel, and will input this expertise. UIC will contribute

knowledge of standards and their application in rail-wheel interface management across their member countries. The project will also consider the existing UIC Wheel Rail Conditioning project led by ProRail. The work will particularly consider lubrication systems appropriate for low density lines.

There were some differences from description of work where UIC was supposed to contribute knowledge of standards and their application in rail-wheel interface management across their member countries. Because this data was not received on time some manufacturers contributed their standards and certificates. The project is supposed to consider the existing UIC Wheel Rail Conditioning project led by ProRail. This will be provided in the second deliverable. The work particularly considers lubrication systems appropriate for low density lines. This will be performed and explained more detailed in the deliverable D2.8.

There was one deviation related to date of completion. Delivery date of the D2.7 was M18 and there was about two-month delay on this deliverable. The deliverable D2.7 needed additional data of the standards about lubrication and lubricators. Unfortunately, at this time data was not available from UIC and therefore only the case studies in Turkey and Slovenia were considered. With the input by some other participating manufacturer the deliverable was completed.

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Abbreviations and acronyms

Abbreviation / Acronym	Description
TOR	Top of rail
EU	European Union
TORFC	Top of Rail Friction Control
RCF	Rail Contact Fatigue
FM	Friction modifier
IM	Infrastructure Manager
PW	Plastic wheel
MGT	Million Gross Tons
E	Electrical
HST	High Speed Train
D	Diesel
DE	Diesel Electrical
(AAR)	Association of Railroads
SZ	Slovenian Railways
USFD	University of Sheffield
AFER	Autoritatea Feroviară Română
TCDD	Turkish State Railways

1 Task Description

T2.5.1 Lubrication systems and data, INTADER will lead the task based on the experience and needs for lubrication on their network. USFD have experience of the effect of lubrication on rail-wheel contact, especially wear rates of track and effect of reliability in lubricant application on fatigue life of rail steel, and will input this expertise. UIC will contribute knowledge of standards and their application in rail-wheel interface management across their member countries. The project will also consider the existing UIC Wheel Rail Conditioning project led by ProRail. The work will particularly consider lubrication systems appropriate for low density lines.

2 BACKGROUND

To stay competitive with other modes of transportation, today's railroads need to reduce costs and minimize capital investment. Two major ways to accomplish this are by conserving energy and reducing rail and wheel wear through more efficient lubrication of the wheel-rail interface.

Correct and proper management of the rail–wheel interface helps the rail industry to reduce wear and fatigue, which results in enhancement of asset life, growing of rail industry's business and improving reliability of service. In the case of railway curves, properly and efficiently applied lubricants decreases squeal on corners and reduce rail noise. Similarly, correctly applied lubricants can reduce wear on track and wheel, particularly on the contact zone on the outside curve.

Wear has a detrimental effect on rail and wheel life, and adds to maintenance costs. Rail and wheel defects, breaks and derailments cost the rail industry each year due to cancelled and delayed traffic, emergency maintenance, loss of assets, loss of revenue etc.

Lubrication is one of the most effective maintenance programs to reduce wear, energy consumption and noise. There are several types of lubrication systems to provide uniform film thickness at the wheel-rail interface and effective transport mechanisms for the grease must be better understood and managed which will be covered in this deliverable, widely used in the rail industry. The important thing in selection is to select the correct lubricant, lubricator, and placement model by taking into account **the weather conditions**, track characteristics, dispensing equipment, type of lubricant and maintenance activities.

Locomotive on-board lubricators transfer grease indirectly from the wheel to the rail. The success of this method depends heavily on the transport mechanism, which is directly influenced by many factors including wheel and rail contour, rail geometry, dynamic characteristics of the truck, surface conditions of the wheel and rail, the viscosity and lubricity of the grease, operating temperatures of the wheel and rail, and environmental factors such as temperature and precipitation. Indirectly, the transport mechanism can be influenced by the operating characteristics of the lubricators, train action, wheel slip, environmental contamination, and human factors. The same parameters affect wayside lubrication of the rail. Lubrication can be successful only if the transport mechanism is handled in an effective manner. Lubrication of the gauge corner at the rail is a direct lubrication method. However, it is still heavily influenced by a number of parameters that can inhibit the maximum effect of lubrication, including the frequency of trains and lubrication passes and the amount of lubricant applied.

3 LUBRICANT EFFECT ON THE TRACK

Lubricants are generally outstanding in reducing wear in harsh interactions. However, other aspects should be taken into account before lubrication.

In the years 1954-1960, several studies had been worked on, and lubrication and improving rail materials had been compared. It was recommended by Dearden to decrease the number of sharp curves on domestic railways as much as possible to reduce the wear. Because maintaining a lubrication system used to have higher costs.

In 1970s, several studies on measuring wear at rail gauge face and wheel flanges were completed. Beside this, while investigating for appropriate lubrication strategies it was also an issue for IMs to save maintenance cost. It was noticed that the wear on the rail gauge face at dry conditions was 0.37 mm/MGT (million gross tones), while lubrication led to ~9 times lower wear (0.042 mm/MGT). The outcomes of the study encouraged investments in lubrication systems. Even if, some negative experiences such as immigration of lubricant to rail.. etc were known, a significant interest arose in 1970-1980. Also, the effect of water on friction was another issue to be investigated in 70s. After a comprehensive investigation, it was noticed that water was one of the main factors affecting the friction between rail and wheel. A critical mixture of debris and water can give enough slurry viscous to diminish friction coefficients down to 0.015. When raining, the friction coefficient becomes almost 0.2.

Lubricant type, additions to lubricants, and the amount of lubricant are influencing factors on wear control. A field test which was carried out at Facility for Accelerated Service Testing in Pueblo, Colorado, to observe if different types of grease and the added quantity of solid lubricants affected retentivity and spread ability. A laboratory test with a full-scale wheel/rail test machine showed that the durability of lubricants at the rail could be best improved by using more viscous lubricants. Adding solid lubricants also improved durability.

Also, a field study to investigate spread ability was carried out at a commuter train in Stockholm. The case study line had radii about 600m with one-way traffic. The worn off volume was 0.5 mm2/MGT at a distance of 50 to 150 m while the wear rate was twice as high (1.1 mm2/MGT) at the distance 250 m from the lubricator. A similar curve without lubrication resulted in much higher wear (2.4 mm2/MGT).

It should be well understood that there are many factors affecting lubrication effectiveness. One of the significant factors affecting wear rates on rail/wheel is lubricant type. Even though having the best lubrication system, it may not perform well due to not covering the demands of operation conditions. In conclusion, lubricant type has a significant role and the optimum lubrication which should be adopted must regard the operation conditions.

4 BENEFITS OF EFFECTIVE RAIL LUBRICATION

It is known that lubrication has a significant effect on reducing rail-wheel wear. For this reason, a wheel flange lubrication project was developed at TCDD.

A rail-wheel flange lubrication system is a system that lubricates between rail head and wheel and between the wheels of wagons and bogie. While reducing the rail and wheel wear through lubrication, it is also seen that the fuel consumption reduces 5%-15%. So that, it is seen that the rail life increased 45% on alignments, 150% on curves, also the wheel life increases 50-55%.

Since 1987, TCDD carried out several studies. Also, there are several studies which are in progress and continue in collaboration with different companies and manufacturers.

In 1998, the company REBS supplied 250 unit lubricators to TCDD, and today the number of the locomotives that have lubrication systems is 640. Since, TCDD has started to use lubrication systems and as result of them, TCDD stopped welding flanges, and gained great savings due to reduced rail-wheel wear.

These are the benefits that TCDD has experienced since it has started to use lubrication systems at its network;

- Increased rail and Wheel life due to reduced wear
- Reduced derailment due to increased safety
- Reduced fuel consumption between 5-10%
- Reduced workmanship as result of avoiding bogie welding
- Reduced material cost due to avoiding bogie welding
- Increased wheel life
- Reduction in other defects arising from installing and removing the wheels from wagons and locomotives

Universal benefits of lubrication are as follows;

- Reduced flange noise
- Reduced rail- wheel wear
- Reduced energy consumption
- Reduced RCF development
- Cost-Benefit
- Reduced derailments

5 ECONOMIC ASPECT

As a result of effective lubrication studies, it is known that the improved wheel/rail friction control has significant, positive benefits for the rail industry. It was realized that a generous benefit can also be gained by improving lubrication techniques and maintenance of lubrication systems. These benefits are significantly coming from increased rail life/ wheel life, and fuel/ lubricant consumption.

In the early 1980s the fuel consumption wasn't an issue for TCDD. The only focus was on decreasing rail/wheel wear by lubrication. After putting lubrication into practice, the maintenance department realized that the wheel used to need to be maintained 3 times less.

Even though there wasn't any focus on wear rates after lubrication was put into practice at TCDD, it was realized that during the maintenance periods there was a decrease on wear rates on rails. However, there wasn't any study which provide numerical output. As result of decreased wear on rails, the rail life increased, and maintenance time decreased. Thereby, asset life extended and maintenance cost due to decrease maintenance needs decreased.

After many experiences on different lubrication systems at TCDD, as result of a study which was carried out for proving the lubrication effect on fuel consumption, the save of fuel consumption when lubricating was about 5-10 %. This differentiation used to change according to dispatchers of TCDD, curves at tracks, inclines… etc.

6 EFFECT OF LUBRICATION ON RAIL-WHEEL CONTACT

Rail and wheel are capital intensive assets for any railway and the adoption of proper maintenance strategies will impact on the life and maintenance cost of these assets. Maintenance of railway has a significant effect on RAMS. Towards the 2050 vision of whitepaper, axle loads are increasing, the length of trains are getting longer and as result, these changes bring some difficulties. The wear rates increase; therefore maintenance cost of rails and wheels increases.

For reducing Rolling contact fatigue, flange noise, short wave corrugation, managing friction coefficient periodically can be beneficial. Another aspect of managing friction coefficient can be energy saving and steering performance of trains. To enable these, adoption of appropriate lubrication strategies for rail and wheel should be considered.

Rail and wheel are capital intensive assets for any railway and the adoption of proper maintenance strategies will impact on the life and maintenance cost of these assets. The investment in rail maintenance has a large impact on the reliability, availability, maintainability and safety (RAMS) of rail operations. Increased axle load and longer train length bring challenges in the maintenance of rails and wheels due to increased track deterioration and wear.

Lubrication and friction management have been used commonly for controlling lateral rail and wheel flange wear (1) where they have been shown to (2):

- Reduce wear rates in tight curves by a factor as high as 10 when compared to dry unlubricated contact
- Reduce wheel wear
- Reduce the risk of new or recently profiled wheel flanges climbing the gauge face of the rail
- Reduce traction coefficient and thereby limit the initiation of rolling contact fatigue and gauge corner cracking
- Reduce the frequency of insulated block joint failures by reducing the metal particles in the environment.

Typically, the lubrication between the flange and the railhead is applied on all curves which have histories of gauge face wear and those of radii less than 1000m or cant deficiency of greater than 50mm (2).

The application of rail friction modifiers to the top of the rail is still in its earlier stages, laboratory testing and localized field trials demonstrate that such application can have a positive effect in reducing rolling contact fatigue and spalling on very tight curves, wear and plastic deformation, lateral forces and energy consumption.

Consistently maintaining the friction coefficient at required level can help to reduce the wear, the development of Rolling Contact Fatigue (RCF), the development of short wave corrugation in curves and noise levels. It can also help to improve the steering performance of vehicle and relative energy savings. The required friction coefficient can be achieved by proper lubrication

of the rail/wheel interface. However, the reliability of the application can be critical and interruption of the supply of lubricant can have a significant impact on the growth of fatigue cracks and the failure of the rail steels, depending upon the lubricant type. It has been found that lubrication is required for cracks to initiate, so surface damages can be worn away when the rail is dry, but when water lubricated it there can still be enough plastic flow result in RCF cracking. A study by Fletcher and Beynon, 2010 carried out laboratory testing of a molybdenum disulphide and water lubricants on pearlitic rail steel and with each applied the lubricant intermittently rather than continuously. The solid molybdenum disulphide stick type lubricants have been able to maintain low friction conditions over long periods and the absence of large cracks was attributed to these lubricants not penetrating the cracks, whereas liquid based lubricants did result in surface cracks. For the application of lubricants intermittently it was found that with the molybdenum disulphide lubricant a rapid mode of rail steel surface failure was experienced after the application of the lubricant, this was not found with the experiments with water as a lubricant.

6.1 EFFECT OF RELIABILITY IN LUBRICANT APPLICATION ON FATIQUE LIFE OF RAIL

It should be well understood that there are many factors affecting lubrication effectiveness. These are lubricants, traffic direction, performance of lubricator, applicator bars and their locations.

Railway operations differ from each other worldwide. Transport and retentivity of lubricant on the rail are affected by different factors which differ from each rail operator and IM. These influencing factors can be defined as;

- Curve radii
- Tangent lengths
- Track gradients
- Traffic type and wear state
- Train speed and braking requirements
- Axle loads
- Rail types
- Rail grinding strategies
- Climate
- Traffic type
- Traffic load

Proper application of wayside lubricators also includes appropriate equipment selection, suitable lubricant for the particular operating condition, measurement and management of the lubrication effectiveness, positioning of lubricators, and maintenance.

Due to the fact that wayside lubrication is cost effective and easy to operate, it is adopted by many IMs. As mentioned above, effectiveness of lubrication can be affected by many factors such as length of curve, curve radius, tangent track, lubricant properties, type of applicator bars (short and long), use of single pair or double pair bars, applicator bar height from top of rail, application rate, train direction (bi-directional or uni-directional), locomotive truck wheelbase, axle load, speed, track alignment factor, train braking, bogie type, sanding, gradient, wheel–rail profile, rail–wheel temperature, contamination and climate.

The placement of wayside lubricators is dependent on bar type (long or short), bar height below the top of the rail, placement in tangent or curve spirals, track gauge at the lubricator site, grease application rates, RCF present on the rail surface, optimal dispensing rates to minimize splash, and effective grease carry distance (coefficient of friction).

There are several types of trackside lubricators. These are mechanical, hydraulic and electric lubricators. Cause of improved application accuracy and effective lubricant consumption so that reliable application, the electric lubricators has the best performance. Also, the electric lubricators have remote sensing technology which enables to plan maintenance related to the time intervals and location.

6.2 WEAR RATES OF TRACK

Friction between rail and wheels induces the wear on rails. Asset life and performance of rails and wheel are affected by wear. Especially on the high rails of sharper curves gauge side wear is a common problem of IMs.

There are several factors affecting wear such as;

- axle loads
- lateral forces
- longitudinal force
- creepage
- curve radius
- gradient of the track
- cant/super elevation
- track gauge
- surface conditions of the wheels and the rails
- train speed
- train length
- frequency and type of trains
- rolling stock performance
- operational and environmental issues

As a result of studies at Association of Railroads (AAR), it was estimated that wear and friction occurring at the wheel/rail interface due to ineffective lubrication costs American Railways in excess of US $ 2 billion each year.

7 FRICTION MODIFIERS AND LUBRICANTS

A friction modifier consists of a water-based suspension of dry solid materials with no liquid oil or lubricant content. The water acts as a carrier and evaporates, leaving the dry FM particles in the third body layer between wheel and rail. These dry FM particles mix into the third body layer providing an intermediate coefficient of friction between the wheel and rail This intermediate friction level (0.3-0.4) is lower than dry rail but significantly higher than lubricated conditions. Consequently, lateral forces will be reduced, vehicle steering capabilities will be improved and damage on wheel and rail will be minimized without negatively impacting acceleration or braking capabilities. The Technology Transportation Centre Inc. (TTCI) in the US defines a friction modifier as a product designed to provide one intermediate friction level over a range of material application rates and/or hold the friction constant over a specific range of wheel-rail creepage.

A FM will also provide positive friction characteristics between wheel and rail over an extended creepage range. This refers to a positive slope of the traction / creepage curve over all relevant creep levels. In dry contact conditions the negative slope of the traction-creepage curve can give rise to stick-slip oscillations at creep levels close to the maximum of the curve. Given certain boundary conditions (wheel-rail surface roughness, dynamic excitation) wheels can start to oscillate between these two creepage conditions causing noise issues (squealing noise) and damage development (corrugation). The positive friction characteristics of the FM will prevent this oscillating effect from happening.

A FM treated rail-wheel contact will reduce the friction level and will provide a positive traction-creepage relationship thereby preventing stick-slip oscillations from happening.
Recently, alternative materials that are lubricant based (oil, grease, hybrid) and therefore provide inherently low coefficient of friction (<0.2) have also been promoted for TOR application. These materials are not friction modifiers as they provide completely different friction mechanisms between the wheel and rail. This material type provides reduced friction conditions through a boundary or mixed lubrication mechanism where the achievable friction value is strongly dependent on the amount of material present between wheel and rail. Such materials do not dry under normal conditions but rather are consumed by the wheel-rail contact conditions. Consequently, for these non/slow drying materials there is presumably always a liquid phase present between the wheel and rail until the material has been completely consumed.

7.1.1 Friction Management Guidelines

American Railway Engineering and Maintenance of Way Association (AREMA) recommends as follows ,

- Gauge Face friction values should be < 0.20
- Gauge corner friction value should be < 0.20 which was under review
- Top of Rail (TOR) friction value should be 0.35 +/-0.05
- Left to right rail friction value differential should be < 0.1

The Canadian Pacific Railway recommends as follows,
• Maintain top of rail friction coefficient differential, left to right < 0.1
• TOR friction coefficient should be $0.3 \leq \mu \leq 0.35$
• Gauge Face of high rail coefficient of friction ≤ 0.25

8 SELECTING THE OPTIMAL TYPE OF LUBRICANT FOR THE PARTICULAR OPERATING ENVIRONMENT

It is known that lubrication on rails/wheel reduces wear rates and contributes cost savings. Which is more important than lubricating rails/wheels that manage to effective lubrication which covers the demands of operating conditions. Therefore, choosing appropriate lubricant has significant impact on the performance of lubrication as well as choosing appropriate lubrications system.

On TCDD's network, due to further demands of TCDD a new lubrication system had been developed in collaboration with a lubrication system manufacturer. The new lubrication system covered the technical requirements. However, it was noticed that the performance of lubricant didn't perform well, and TCDD decided to use an alternative lubricant which works better on TCDD network.

There are several characteristics affecting the performance of lubrication. However, it can be said that there are three key characteristics of lubricants that impact performance especially in trackside systems. These characteristics can be defined as lubricity, retentivity and pumpability.

1.Lubricity; it is defined as the capacity of lubricant for decreasing friction coefficient. The poorer lubricity results higher wear rates on rails/wheels. The wear rates under dry conditions result higher magnitude than the operation under lubricated conditions. It should be ensured that the lubricant is applied to required location with sufficient amount.

2. Retentivity; is a measure of the time (or number of wheel passes, or MGT) that the lubricant is able to retain its lubricity. Laboratory tests show that retentivity decreases with increasing load and increasing lateral creepage (angle of attack).
The practical implication of this is that loaded trains consume ("burn") lubricant at a much higher rate than empties, and that lubricant is consumed much faster in sharp curves than in mild curves.

3. Pumpability is the continuous delivery of lubricant to the wheel/rail interface. The importance of maintaining a build-up of lubricant cannot be over-emphasised. Ensuring that lubricators are not allowed to go dry or to be shut down for extended periods of time is a key factor. Additionally, preventing gauge face wear in curves depends greatly on their ability to be pumped at all temperatures experienced on the railway system, like most fluids the viscosity and hence the pumpability will vary with temperature, although many products have been developed to provide near constant visocity over a range of temperatures.

SZ also has a strong interest in lubrication performance and plans to perform on site testing to validate different types and methods of lubrications under different climate conditions relevant to Southern Europe and will be testing new eco-friendly lubrication (Many older track grease products are carcinogenic and must be withdrawn. New products often behave very differently). This research is supposed to answer the question of which lubricant should be applied.

9 METHODS OF RAIL-WHEEL LUBRICATION

There are three lubrication methods in use by railways around the world: wayside, on-board and hi-rail lubrication.

9.1 Wayside Lubrication

Wayside lubrication is widely used lubrication method. It is possible to lubricate both gauge face and top of the rail. Lubricant is transferred to rail through the applicator bars or it is also possible to transfer the lubricant inside holes in rails.

Reservoir tank, grease pump unit, controller, connecting hoses, power supply unit, applicator bars, wheel–axle sensor unit or plunger, and sometimes a telemetry or remote condition monitoring system such as RPM (remote performance monitoring) are the units of a wayside lubrication system. When curves are concentrated in specific locations, wayside applicators are useful.

9.2 On-board/ Mobile Lubrication

Onboard lubrication is a method where the lubricator is mounted on the locomotive, and the lubricant is applied to the locomotive wheel flange. There are two different application types of onboard lubrication. The first one is by using spray systems and the other one is solid sticks.

Spray systems are the most popular system at TCDD and they are commonly used in Europe. It provides fin tuned controls by curve sensing capability. It is applied as a single system per train. When curves are uniformly distributed, locomotive-mounted applications are more useful.

Also, the large install base of solid sticks which is started to be trialed by TCDD provide large volumes of data. So far, the results of the trial is satisfiying. The system is simple, clean and easy to maintain.

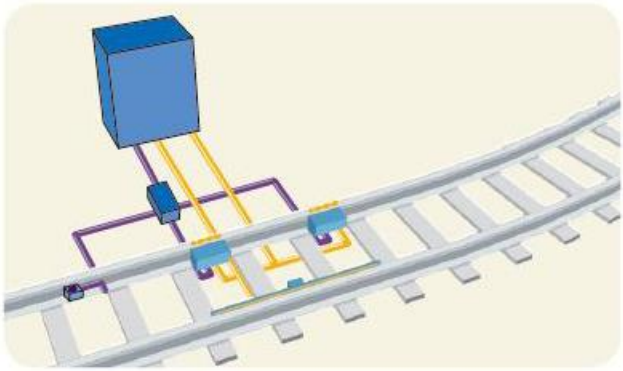
9.3 Hi-rail lubrication

Hi-rail lubrication means the lubrication of the line by the controlled application of a bead of grease directly to the wear face of the rail from a vehicle travelling on the track. The high-rail

vehicle is usually an adapted delivery vehicle, equipped with a special storage and application system (de Koker 2004).

9. TYPE OF LUBRICATION SYSYEMS AND CURRENT RAIL INDUSTRY PRACTISES

9.1 Wayside lubricators



The wayside lubrication method is used for both gauge face application and top of rail application. The whole unit consists of a reservoir tank, grease pump unit, controller, connecting hoses, power supply unit, applicator bars, wheel–axle sensor unit or plunger, and sometimes a telemetry or remote condition monitoring system such as RPM (remote performance monitoring).

9.1.1 Hydraulic lubricators

The main features of hydraulic lubricators are a grease reservoir, grease pump, hydraulic plunger or actuator assembly clamped to the field side of the rail, with a single hydraulic line connected grease pump externally mounted on the grease reservoir, and grease distribution units (applicator bars) and hose system.

As a very simple construction the grease pump is activated with the hydraulic actuator, and transfers grease to the applicator bars when the wheel strikes the plunger. It doesn't require power supply from an external source, e.g. electricity or solar power. It is easy to install and maintain however the weakness is that they require a high frequency of maintenance. Grease is delivered by every passing of the wheels and causes building up the grease.

This system has little control over grease delivery rates, and results in substantial amounts of grease delivered by the unit to the bars. This results in grease waste to the track, and contamination of the top of the rail. These units are installed on the high rail side at the transitions to left- and right-hand curves, and due to their close proximity to the rail they therefore have to be removed before each grinding cycle to prevent damage to the units.

Hydraulic systems are simpler compared to mechanical systems, minimize the number of moving parts, but offers very limited application control, and are better suited to shock

loading and higher speeds than mechanical systems. In general, hydraulic systems are most effective in territories for the speed between 40km/h to 80km/h.

9.1.2 Mechanical lubricators

Mechanical lubricators have the simple design like hydraulic systems, and rely on the same principle of operation as the hydraulic units.

It consists of a grease tank, grease delivery pump and grease distribution unit. With the passage of each wheel over the plunger, the ramp lever rotates, and this lever is connected to the pump through the drive shaft. The drive shaft uses the pressure from the wheel impact to pump lubricant to the applicators.

The entire pumping mechanism is housed in the reservoir, and can be removed for servicing. The grease tank can have different capacities, and applicator bars are also of different sizes.

Like hydraulic systems, this system doesn't require external power supply and precise control of grease application rate cannot be reached.

Due to excessive grease delivery, there is top of the rail contamination and waste to the ballast in the track. RCF can be the result of non-grinding, due to units being left in track each grinding cycle.

9.1.3 Electrical lubricators

Electric lubricators differs from others by precise electronic control, based on axle or wheel count via the sensors mounted beside the rail.

It includes a grease reservoir, electronic controller unit, delivery pump, battery or A/C controller, and distribution bars. To dispense grease on the gauge face or FM to the TOR, system has high pressure, displacement and distribution systems

Lubricators can be used for gauge face and top of rail application. They are available in different specifications of power supply, reservoir size, applicator units and telemetry.

The most significant features of the electric lubricator are:

- Highly reliable and efficient operation
- Application of grease based on the axle–wheel count
- Precise control of grease application rate to reduce lubricant wastage
- Ability to survive for longer periods in harsh weather
- Less total cost of ownership
- Flexibility in grease application due to change of conditions
- Continuous performance in all weather and seasons
- Less maintenance cost and time
- Ability of maintenance personnel to plan daily work based on remote condition monitoring of the units
- Intelligent condition monitoring unit, able to transfer data to remote authority

- Continuous power generation from solar energy or power grid, and rechargeable battery for emergency back-up
- Higher capacity tank in most cases.
- Electric lubricators rely on solar or electric power.

From a field testing using electronic lubricators the advantages over hydraulic and mechanical lubricators are as follows:

- Highly reliable
- Efficient operation
- Inbuilt sensors, intelligent system and electronics application make these units highly capable of performing a wide range of performance requirements based on the needs of different railway environments
- Deliver grease based on precise increments of pumping rates and axle/wheel counts
- Precise control of grease application rate which reduces surface contamination and grease wastage
- More precise lubricant application increases the carry distance down the track with reduced grease quantities
- Fewer units are required compared to mechanical and hydraulic units
- Improved reliability even in harsh climates (extreme cold and heat).
- Less maintenance time compared to hydraulic and mechanical units
- Remote Performance Monitoring system capability which can dramatically reduce the down time of remote units therefore increasing the reliability of lubrication. This feature can generate statistical data, reports, graphical presentation, alarms and warnings with hourly updates for each Individual lubricator.
- Continuous power is available from solar energy or the power grid with a rechargeable battery for emergency back up

Recent investigations on some Australian heavy haul rail networks have determined that grease dispensed from hydraulic or mechanical units was being dispensed to the wheel however it did not carry down the track to protect the rail gauge face. A major portion of the grease is wasted or leaked from the bars and assemblies of mechanical and hydraulic devices. The grease carry distance ends up within short distances from the lubricator and the rest of the track remains unprotected.

9.2 On-Board Lubrication Systems

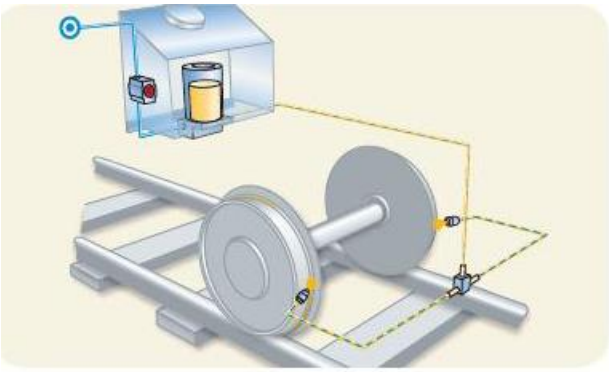
On-board lubricators supply lubricant to the wheel flange – rail gauge corner. In most designs the lubricant is deposited on the wheel flange and spread along the rail, although in some the lubricant is directly applied to the rail. Grease or oil spray systems are used that employ complex control strategies using sensors measuring vehicle speed and track curvature to govern lubricant application. Solid stick lubricators are also available, in which a stick of lubricant is spring loaded against the wheel flange.

On board systems have a number of advantages over wayside lubricators:

- reduced safety risk exposure to staff during installation, inspection and maintenance.

- easier inspection and maintenance (carried out in more controlled conditions).
- the rail will continue to receive some friction control protection in the event of the failure of an individual on board lubricator.

Image.1.1. On-board lubrication system illustration



Despite these advantages, at problem tracks, site wayside lubricators will still be a necessity

10 GENERAL PROBLEMS WITH LUBRICATION

Problems with lubrication systems have been found to be related to both technical and human issues. The main technical problems with wayside lubricators have been highlighted as: blocked applicator openings; leaking holes; ineffective pumps and trigger mechanisms; and poor choice of lubricant. Human related problems can result from the technical issues. If over lubrication occurs and lubricant migrates onto the rail top, adhesion loss can occur. Train drivers may then be tempted to apply sand to compensate and increase friction, however, this will lead to increased wear and could cause the applicators to become blocked. The thought that the application of lubricant will lead to wheel slip can also lead train drivers to switch off on board lubrication systems.

Some of the consequences of poor wayside lubrication have been listed as:

- wheel slip and loss of braking (and potentially, wheel flats and rail burn)
- poor train handling
- prevention of ultrasonic flaw detection
- wastage of lubricant
- high lateral forces in curves and subsequent increase in wear.

Other than adhesion problems, over-lubrication can cause an increase in rolling contact fatigue crack growth on the rail gauge corner. This can be due to pressurisation of the crack leading to increased growth rates or because reduced wear means that cracks are truncated less. However, fullscale test results from narrow curves show that well-maintained lubrication could reduce both the wear rate and the propagation rate of surface cracks

11 KNOWLEDGE OF STANDARTS AND THEIR APPLICATION IN RAIL-WHEEL INTERFACE MANAGEMENT

11.1 REFERENCE Standards for Lubrication Devices

- EN 15427 Railway Applications – Wheel/Rail Friction Management - Flange Lubrication;
- EN 16028 Railway Application – Wheel/Rail Friction Management - Lubricants For trainborne And Trackside Applications;
- EN 13674-1 Railway Applications - Track - Rail - Part 1 Vignole Railway Rails 46 Kg/M And Above;
- UIC 510-2 Trailing Stock: Wheels And Wheelsets. Conditions Concerning The Use Of Wheels Of Various Diameters;
- EN 13715 Railway Applications - Wheelsets And Bogies - Wheels - Wheels Tread;
- ISO 9001 Quality Management Systems

11.2 Reference Standards Or Methods (With Target Values) Requested For Lubricants:

SDS according to EU regulation no. 1907/2006 (REACH) and 1272/2008 (CLP) and EU regulation no. 830/2015

1. **Physical And Chemical Properties According To Standards/Test Method:**

Table 1: Type Of Base Oil: Mineral oils are prohibited, mostly synthetic ester oils are requested

Water solubility (at 24°C)	Insoluble
Hazardous reactive properties	None
Solvents	None
NLGI Class (DIN 51818, ASTM-D 217)	At least 1,5 (better 2)
Dropping Point (°C) (ISO 2176)	>150°C
Water resistance (DIN 51807-1-40)	1
Flash point (EN ISO 2592 or equivalent)	>200°C
Worked penetration (ISO 2137)	290-340mm/10
Determination of oil separation under static (40°C, 7 days) (DIN 51817)	Less than 3%
Anti – corrosion properties (DIN 51802, ASTM D6138)	Non-corrosive
Wear Test (ASTM D 2266), Scar diameter	<1mm
Force of weld of the Four ball test (ASTM D 2596)	Must be over 2500N

Remark: Timken Load Test has been put out of usage (not relevant for greases).

2. **Toxicological effects**

Method OECD 201 and OECD 202: The product must show no toxicity to aquatic organisms.

3. **Persistence and degradability**

Biodegradability: OECD or its equivalent standard: over 60% (At least biodegradable base must be more than 60% biodegradable in 28 days)

Must not contain any of heavy metals or lead oxides.

4. **Product, according to the standard IEC 60093:1980, must not affect electric conductivity when applied on the rail.**
5. **Application temperature: from -30ºC to +80ºC**
6. **Lubricant shall satisfy normal and fluent operation of the lubrication device under -25ºC**
7. **ISO 9001 and ISO 14001 Quality management systems are demanded from producer.**

12 EXPERIENCE AND NEEDS OF PROJECT PARTNERS FOR LUBRICATION ON THEIR NETWORK

12.1 TCDD case

For more than 40 years TCDD has been experiencing different kind of lubricators, and lubricant as it has been known the benefits of lubrication on wear, and the cost benefits of operation and maintenance.

The application is not related to the type of traffic, traffic load or climatic conditions. But, each locomotive has an on board lubrication system. The locomotives of TCDD are appointed for a region, and then they are interchanged between the regions when it is required.

First Experience of TCDD/ Company "A":

Date: 1987-1988

Type of system: On-board Lubrication system

Type of Lubricant: Molybdenum disulfide lubricant

Number of test vehichle: 5

Type of test vehichle: DE22.000 (diesel electric loco)

Between the years 1988-1990, the first lubrication system at TCDD was trialled. The system was tested on the five of DE22.000 locos which are diesel electric locomotives of TCDD. It was an on board lubrication system which had 180lt reservoir for grease as lubricant. TCDD

installed the system in the way that the first and the fourth wheels of the locomotives would be lubricated.

The system used to have double channel for transferring grease and air from pump and reservoir to flange. In case of rupturing of one of the channels, system used to fail. If the grease channel was broken, the grease inside the reservoir used to be spilled.

Within this period, TCDD did not carry out detailed studies on fuel consumption, but the decrease of the fuel consumption was noticed.

Table 2 Advantages and disadvantages of lubrication system (A)

ADVANTAGES	DISADVANTAGES
No choking of the circuit due to powerful pump	Noisy due to powerful pump
Easy to maintain	Breakage of channels due to powerful pump
Reduced fuel consumption	There wasn't any feedback/ circulation system on the grease circuit or air circuit.
Reduced wheel wear (about %20-30)	Contamination of the lubricant to the rail, ballast.. etc when the grease channel was damaged
System requires maintenance every 2 years	Wheel spinning when lubricant contamination happened

After lubrication, the oil film on rails and flanges was visible. Even this early system had benefits, the most problematic issue was that the system didn't warn the user when the oils ran out. So, bleeding of the circuit, and adjustment of injectors was required to restart the system.

Experiment-2:

Date: 1989-1990

Type of system: On-board Lubrication system

Type of Lubricant: Oil

Number of test vehichle: 2

Type of test vehichle: E43.000 (electric loco)

TCDD engineers gave great importance to lubrication. So, other lubrication systems from other companies were tested. One of them was tested between the years 1988-1990. Mechanism of the flange lubrication system was easy, didn't require air or oil hose. The system used to have a small plastic wheel which was used to lubricate wheel flange. Within the test, guide wheels (1&6) of double cab locos were lubricated. Amount of lubricant wasn't considered.

Table 3 Advantages and disadvantages of lubrication system (B)

ADVANTAGES	DISADVANTAGES
Decreased wear rate on rails	Breaking of plastic wheel
Increased wheel life	High workmanship cost
Easy system (neither oil hose nor air hose)	High replacement cost
Decreased fuel consumption	Contamination of oil after breaking of plastic wheel
Sufficient application	Laborious to maintain

TCDD wasn't satisfied with the performance of this system. Many plastic wheel breakages happened. TCDD workmen spent many hours to replace the plastic wheels. Beside the long time spent on the replacement of plastic wheels (PW), in case of breakages of PWs caused contamination of lubricant to rail. Therefore, it had been noticed that the wear arising from wheel spinning on rails decreased. TCDD didn't adopt that system.

Experiment-3

Date: 1988-1990

Type of system: On-board Lubrication system

Type of Lubricant: Graphite based bitumen grease

Number of test vehicle: 2

Type of test vehicle: DE24.000 (Diesel electric loco)

This system was tested on one DE24000 loco of TCDD. the first and the fourth wheels of the loco were lubricated. The system comprised of a separate grease and air circuit system. There wasn't any warning or automatic switch off system.

Experience;

- Choking of the circuits
- Waste of grease/ air in case of breakage of hoses/ channels
- In case of breakage of hoses, it was noticed that the contamination of grease to bogie, rail, ballast... ect
- Difficult to maintain
- Unwanted by TCDD workmen

Graphite based bitumen grease was declared problematic by workmen of TCDD. It was noticed that, the grease built up an oil film which was visible. On the other hand, the graphite based bitumen grease penetrated below the skin.

Table 4 Advantages and disadvantages of lubrication system (Experiment-3 lubrication system)

ADVANTAGES	DISADVANTAGES
Decreased wear rate on rails	Penetration of grease below the skin
Increased wheel life (up to 30%)	Separate air and grease hose
Good oil film	Choking of the circuit
Decreased fuel consumption	Contamination of oil after breaking of plastic wheel
Easy to maintain	Laborious to maintain

After tests, TCDD didn't adopt the system mainly because of the complaints of workmen.

Experiment-4:

Date: 1990

Type of system: On-board Lubrication system

Type of Lubricant:

Type of test vehichle: DE24.000 (Diesel electric loco)

This system was acknowledged for testing by TCDD, but the company didn't manage to supply the suitable lubricant. It wasn't tested.

LUBRICATION STUDY ON FUEL CONSUMPTION

Case Study Line: Marşandiz Gar- Yerköy

Distance: About 364km

Date: 1993, April

Vehicle: DE24.000

Net-Tonne: 800 T

Number of axle: 40 & 42

- After vehicle, which has on-board lubrication system on, was fuelled from Marşandiz, and left for Yerköy. The consumed fuel was notd.
- Another vehicle, which didn't have lubrication system, was fuelled and left for Yerköy. The consumed fuel was noted.

Constants For First Test

- Dispatchers

- Route
- Vehicle
- Axle load
- Net-Tonne

For Seconds Tests,

- Dispatchers were changed
- Route was same: Marşandiz- Yerköy
- Axle loads changed from 40 to 42
- Net tonne was same :800 T

Third Test

First vehicle had to idle because of traffic for 30 minutes at the station. Therefore, the second vehicle was waited under the same conditions for 30 minutes and left.

Results

- It was proved that the fuel consumption when lubricating was lower than when it wasn't lubricating. The saving in fuel consumption was about 20%
- Fuel consumption changed related to dispatcher.
- There wasn't any proven effect on wear rates during tests.

Experiment-5

After many tests, and studies on on-board lubrication, TCDD decided to start a collaboration with a lubrication company for developing tailored lubrication system for TCDD. Best experiences, needs and deficiencies were discussed.

Demand of TCDD were as below;

- Grease/oil and air would be transferred inside the same channel
- There would be no remaining pressure in circuit
- In case of any breakage/ damage of circuit, system would be shut down automatically, and machinist would be warned via LEDs.
- In case of decrease of grease level in reservoir, system would indicate low level
- It would be ensured that the whole system worked correctly, and could be monitored There would be a calibration button to calibrate the system.
  In case of any choking happening, if the user pushed the button 4 times, it would correct the system
- It could be adjustable for lubrication in 100m-1000m intervals, because there was not an accurate application distance information or study. Only authorised person could adjust the distance intervals.
- When train reached the curves, the curve sensors would decide to lubrication intervals
- In curvy areas the both of high and low rail would be lubricated.

Beside these demands, there wasn't any demand related to traffic type, traffic load or curve radius.

This system was developed in collaboration with the company, and TCDD started to use the system on 190 locomotives including DE22.000, DE24.000, E43.000 locomotives.

Table 5 The specifications of the lubricant which has being used up to today is specified below;

Specifications	**Required Values**	**Test**
Worked penetration (25C) min	475 1/10mm	DIN ISO 2137
Operation temperature	-40/ +100	-
Solid lubricant (graphit) min weight percentage %	7	-
Solid lubricant (graphit) max grain size percentage	15	-
Welding Load (Newton) min.	3000	DIN 51350-4 ASTM D2783

After a while, it was noticed that the graphite inside the grease precipitated, due to this precipitation the system choked. Even if the air was bled, system could not be restarted. Therefore, TCDD has decided to use a lubricant which doesn't cause precipitation inside the reservoir.

Today, TCDD has on board lubrication systems almost on its locomotives. The number of the locomotives which have lubrication systems on are detailed below;

Table 6 The table shows the number and type of locomotives which have lubrication systems, and also the suppliers of lubrication systems

Number of the Loco Having On-Board Lubrication System	Type of Loco	Supplier
12	MT 15000	BEKA
24	MT 30000	BEKA
12	HST 650000	BEKA
20	DE 36000	REBS
80	E 68000	REBS
32	E 23000	REBS
6	HST 80100	BAIER&KÖPPEL
1	HST 80000	BAIER&KÖPPEL
86	DE 22000	REBS
160	DE 24000	REBS
89	DE 33000	REBS

45	E 43000	REBS
33	E 22000 (IZBAN Suburban)	REBS
40	E 22100 (IZBAN Suburban)	REBS

On-Board Solid Stick Lubrication Experiment

In 2016, TCDD has started to experience solid sticks for lubrication. These systems don't require a significant maintenance and workmanship, it is easy to use. It has been mounted on two locos "DE 36000" of TCDD. Now, the system is in test phase. The feedback until today is the performance is satisfactory on wear, and easy to use and maintain.

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Figure 1 Solid Stick lubricators that TCDD is testing now

Figure 2 Solid Stick lubrication system that TCDD is testing now

12.2 SŽ CASE

Slovenian Railways has busy passenger, low density passenger and freight dominated traffic types at its network. The maximum and minimum ambient temperatures between the years 2009-2014 are -0,17°C to 19,3°C.

Both on-track and on-board lubrication systems are used by SZ;

12.2.1 On -Track lubrication

SŽ is using stationary track side lubrication systems namely first and second generation of CL-E1, where the mode of dosing is with borings made into the rail, with usage of the material KL-trinAl (more than 100 units). Still, this first generations are still now more advanced and gives much better results than any other lately developed systems from other lubrication companies. For instance, in Slovenia there are few tracks with very high inclination where at such circumstances there would be no possibility to have a safe traffic if using soft lubricants for track lubrication.

Even though SŽ railways haven't done any analysis yet regarding wear reduction, they aware of good results from it, but it must be measured from Czech Railways, where with usage of dosing blades as a worse method of dosing (not with borings) the life period of rails has been prolonged for 2 times. With usage of borings into the rail it is expected that it must be at least 3 times prolonged.

SŽ implemented last year CL-E1 system (ws BA »top« version) at location PTUJ, for preventing of noise from the braking of wagons before the stop station, where braking effect must be fully maintained, and it has been proven, that there is no problem with braking, and noise from braking of wagons has disappeared. Here a special material DBM (ester based with high content of solid particles, more than 50%) has been used.

There is one research study from SŽ for usage of the stationary system, CL-E1, which has been installed for special railway shunting area in Maribor, where the wear rates of rails was huge because of operation with some special wagons with very small wheels. Also, there is a report from SŽ regarding using of borings for last 14 years at SŽ tracks, where there was no breakages of rails where borings have been done into the rails up till now. So this method of dosing showed to be very reliable, where the material comes exactly to the point that you need it (optimal consumption of the material).(Annex-3)

Different kinds of ELPA's track lubrication systems have been used all over Europe, where it has been developed already third generation of them (at the moment the most advanced technology for distribution of solid lubricants). The main idea is to use technology (devices) which are in the position to transfer ("swallow") the material which is very high pressure resistant, because only such a kind of material can give the required result. The same material is used at all climate conditions, the consumption is very little (so you need to fill the device from one to few times per year-depends on frequency, but not every 14 days as this is mostly the case at other providers), that is why the maintenance costs are low. The system is not clogging and does not causes any risk at the tracks (like this is an example with soft lubricants which cause slippery and boxing at the rail at the start of driving of the train).

The new generation of material type DBM-KL, which has been used in Europe on tramway tracks, with very good results regarding braking effect (at emergency braking of tramway the result was even better with this material than without), there is no slippery effect, good noise reduction achieved (curve noise, friction noise), good distribution alongside the track, etc. ıt is expected that wear rates reduction of the rails will be even higher than with previously used material KL-trinAl.

Slovenian Railways has installed in the last year a "top of rail lubrication" lubrication system lately developed by Elpa, type CL-E1 ws BA TOP on the track, where the braking effect shall be fully maintained as the system is mounted before the stop station, the system also prevents from the squealing of wagons during braking before stopping, where this particular noise was completely reduced, characteristics of the system are as follows:

CL-E1 ws BA- recently developed and modernized wayside track lubrication electro system:

- Enables distribution of the most efficient and environmentally friendly CHFC (composite heavily fluid compounds) materials with high content (more than 40%) of solid particles (as for instance material type DBM-KL or DBM-50).
- Piping system of the device (tube divide) while being in a period of inactivity (in standby mode) is not under the pressure.

- Patented technology enables that dosing points could not be clogged even under the heaviest conditions of operation.
- Amount of the dosage of the material for each dosing point is individually and / or jointly adjustable.
- The total dosing amount can be adjusted mechanically and / or electronically.
- Distribution of the material is equal and stable regardless of the material used, under all circumstances (since no sensitive parts are needed for distribution of the material as for instance some progressive distributors or magnet valves, which are able to work only with less efficient but very sliding (slippy) soft lubricants).
- The device provides the ability to read the statistics of the number of driven axles over the dosing field.
- The device is able to dose the same amount of the material at all weather conditions and outside temperatures.
- The device is able to use the same CHFC material throughout the entire year.
- The device enables detection of the vehicle driving directions.
- With usage of CL-E1 device the reduction of LCC (life cycle costs) of rails and other contact parts (like switches, arrows...) is substantial.
- Enables wide range of power supply options (electrical grid, solar panel, train grid + convertor…).
- Enables an option of wayside or underground installation.
- Device enables also distance remote control on customer request.

When using CHFC material (like type DBM-KL):

- Ensures at least from 2.5 times to 8 times of prolongation of rails life-time in supplied area.
- Depending on the method of dosing the noise reduction up to 30 dBA can be achieved.
- Already minimal quantities of the CHFC material ensure total annulation of high frequency noise (squealing) at supplied area.
- Prevention from slippery on the supplied tracks (high safety for maintenance workers, walkers, bicyclists, cars) is ensured.
- Same CHFC material can be used throughout the entire year.
- Low consumption of CHFC material (filling of the CHCF material in the tank is maximally up to 2-times per year).
- Visible trace of material on long distance (Carry down effect).

Photos and movie from Schruns, Austria:
https://youtu.be/-LxgBfyv64I

Figure 3 Wayside lubrication system in Slovenia

Figure 4 Wayside lubrication system in Slovenia

12.2.2 On-Board Lubrication

Figure 5 Locomotive with on-board lubrication system (Slovenia Railways)

SZ has been using ELPA, SIEMENS, ANSALDO, SAB WABCO, REPSO, TVT, SKF as on board lubrication systems because the lubrication of the wheel flanges reduce the friction in the arc and thereby extend the life of wheels and rails. Locomotives, shunting locomotives, electromotive train set, diesel motorized train sets of the SZ are the vehicles which have on-board lubrication systems on whereas wagons are not lubricated. As lubricants SZ has been using oils and grease for on board lubrication. SZ prefers to lubricate all wheel whereas TCDD is lubricating 1st and 4th wheels. Also, other applications are as below,

Table 7 The table shows the suppliers of lubrication systems, the type of system and the type of Train Sets in Slovenia

Supplier	Model	Total Lubricated Train Set
ELPA	BEKA Fluilub	ELOK 363, DLOK 664, DLOK 644; 1.,3. axle and 4.,6. axle
ELPA	BEKA Fluilub	EMU 312, DMG 715; 1. axle of the trolley in driving direction
SIEMENS	SEPULP	ELOK 541; 1. axle of the trolley in driving direction
ANSALDO	DCER 34	ELOK 342; 1. axle of the trolley in driving direction
SAB WABCO	CEDNERON Sa	EMU 310; 1. axle of the trolley in driving direction
REPSO, TVT, SKF	twine soaked in oil	DMG 813; 1. axle of the trolley in driving direction

Figure 6 On-board lubrication system (SZ)

Each system has its own maintenance routine and intervals which was identified by manufacturer.

SZ doesn't have any study yet related to Cost benefit of lubrication but, the effects of on-board lubrication at SZ are indicated as;

- Less friction between wheel and rail
- Longer braking distance due to less friction
- Less noise
- Less friction

12.2.3 Consumption of lubricant per year:

- soft grease - CICO 1500 TL - 2520kg - cca 50000€
- soft grease - SINTONO TERRA SK - 600kg (testing phase) - 12000€
- soft grease - TRAMLUB - 1380kg - cca 23460€
- oil - verigol - 500l - 1500€

The cost of maintaining the lubricating system and replenish the system with lubricant per each batch of approximately: € 60,000.

Saving for SZ wheeled vehicles is about € 5,000 per vehicle.

12.2.4 Problems

The problem of mostly all lubrication companies is, that they offer lubrication equipment which was initially meant for industrial lubrication (where lower friction coefficient is requested to achieve good sliding). This kind of equipment can distribute the materials (soft greases) with very small or no content of solid particles.

Since there is no technology on the existing market, which could distribute the material with high contents of solid particles such kind of technology has had to be developed.

The industrial lubrication providers who use progressive distributers and some magnet valves are aware that they are not in position to use products with high content of solid particles, that is why they invented some new methods and new descriptions, which are afterwards incorporated into the open tenders from railways, that only one or two companies can achieve. It is described the main disadvantages of hydraulic systems is that tubes are all the time under the pressure (also at stand- by mode).

Providers of lubricants also discuss friction coefficients that they can achieve, however, this is theoretically and practically impossible to measure, in operation in the field as there are no prescribed methodologies to achieve this.

Static Friction coefficient “steel to steel” is from 0,12 to 0,30; if moving, the dynamic friction coefficient is 0,10! Soit is unlikely that lubrication companies with soft greases can reach friction coefficients from 0,3 to 0,4?

The spread of materials also presents challengesin case of soft lubricants or water based it is about fleeting of material which can not be transferred on longer distance. Also the rain can easy wash them from the rails. Carry down effect can be achieved only with some ester based material as a carrier and with solid particles being stick onto the rail surface in thin film.

If you use the synthetic ester oil (which is about 65-70% biodegradable and has very good properties- of course is also more expensive- and high content (at least 40%) of special solid particles which are not heavy metals (not some lead, cooper, nickel...) and where such compound is environmentally friendly under OECD 201 and 202 (for not to cause any danger to people, water sources and animals) you can provide WIN-WIN solution for railways. Standards and rules here are not defined exactly.

The important fact of the used lubricant is also its influence on electric conductivity. It is very important for safety at electrified tracks.

There is no EC Directive for railway infrastructure regarding usage of heavy metals, especially lead, nickel and cooper and their oxides in the materials (that should be forbidden as everywhere else like on braking disks in automobile industry etc.) for lubrication as a secondary function and at friction surfaces (like braking linings), where dust comes out in micro particles, so producers use them (this is a case at retarders at marshalling hump railway yards where some producers use for noise reduction at braking of wagons some inserts into the brake shoes, made mostly from lead and cooper, and they pollute in tons of toxic dust which comes from abrasion of those braking segments also into water protected areas and poisoned people around).

12.2.5 Developing System That SZ Knows

DRYproANNSYS: It is a new development, and it is at the test phase. The important thing is, that it is able to use the same kind of material as it is DBM-KL. So, it is expected to produce identical results regarding wear out reduction and noise reduction at wheel flange lubrication.

ELPA d.o.o., which is the manufacturer supplying lubrication system for SZ, has recently developed new (patent pending) on-board wheel flange lubrication system DRYproANNSYS "spray system-ss", with the distance remote data control - for providing data about location of locomotive and about the system operation.

It has a capability to distribute a specific amount of a special composite compound type DBM-OB (with high content of solid particles-over 40%) in a real time to the exact point, where the set-up of different quantity per each dosing point is also enabled.

Direct economic benefit is the reduction of wear out of wheel flanges, as direct ecological benefit is the reduction of noise /squealing/, caused by friction in between wheel/rail contact, especially in curves.

System is distinguished for very low consumption of material, low energy consumption in operation, and works in external temperatures of -60°C to +80°C which is important for colder areas. The reservoir capacity can be adjusted on customer request. An indicator of lateral accelerations inside electronics enables a working program to laterally dose in dependence on speed and on which wheel is burdened in the curve. The prolongation of life span of wheel flanges is expected to be at least four times compared to no lubrication, where the adhesion is fully maintained (no slippery and no sufficient material on the wheels or on the rails). The system is in the testing phase with good initial results.

Figure 7 Elpa On-Board Lubrication System

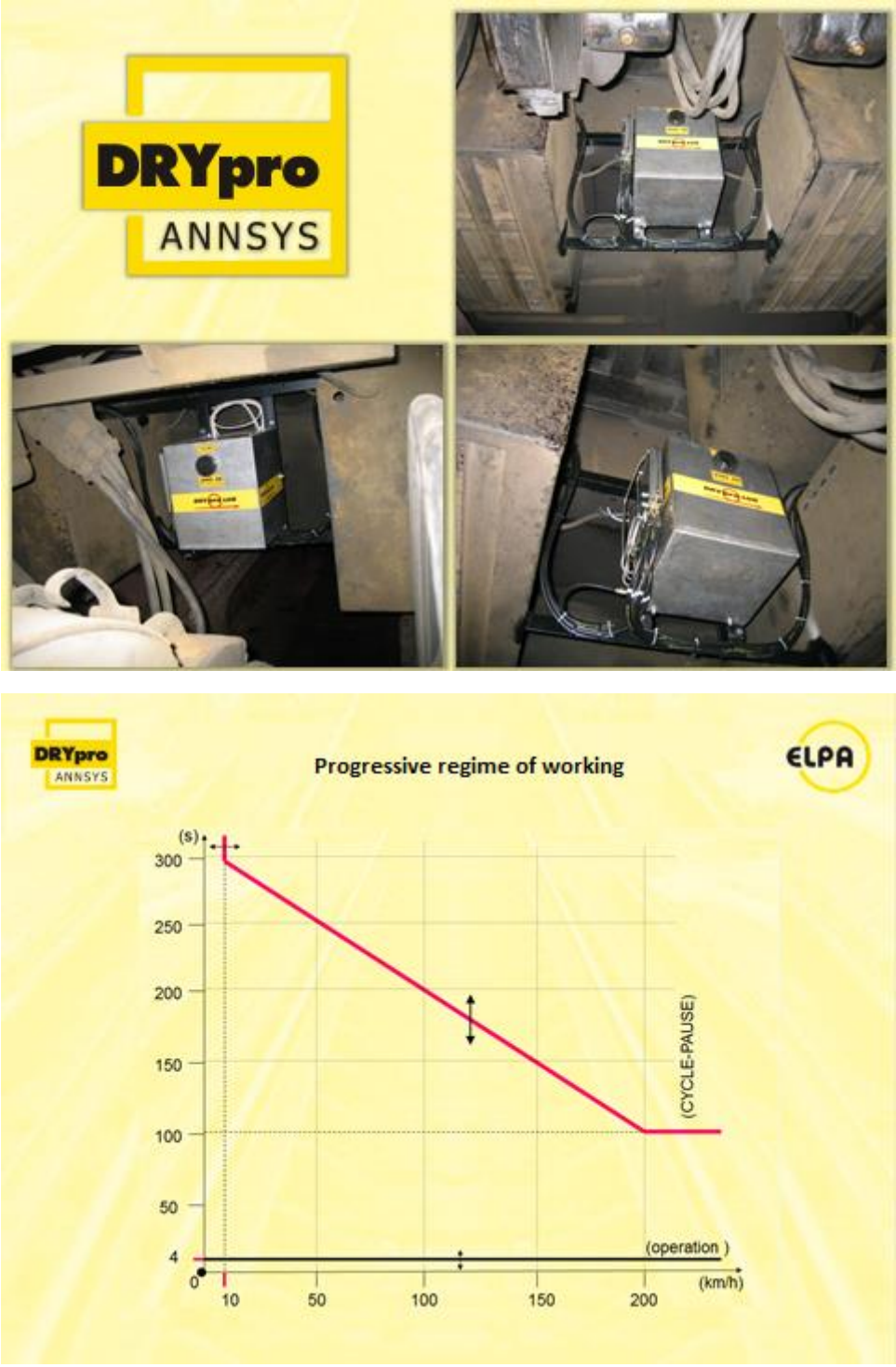


Figure 8 Elpa On-board lubrication system and working regime of the system


DRYpro
ANNSYS
Spray nozzles
ELPA

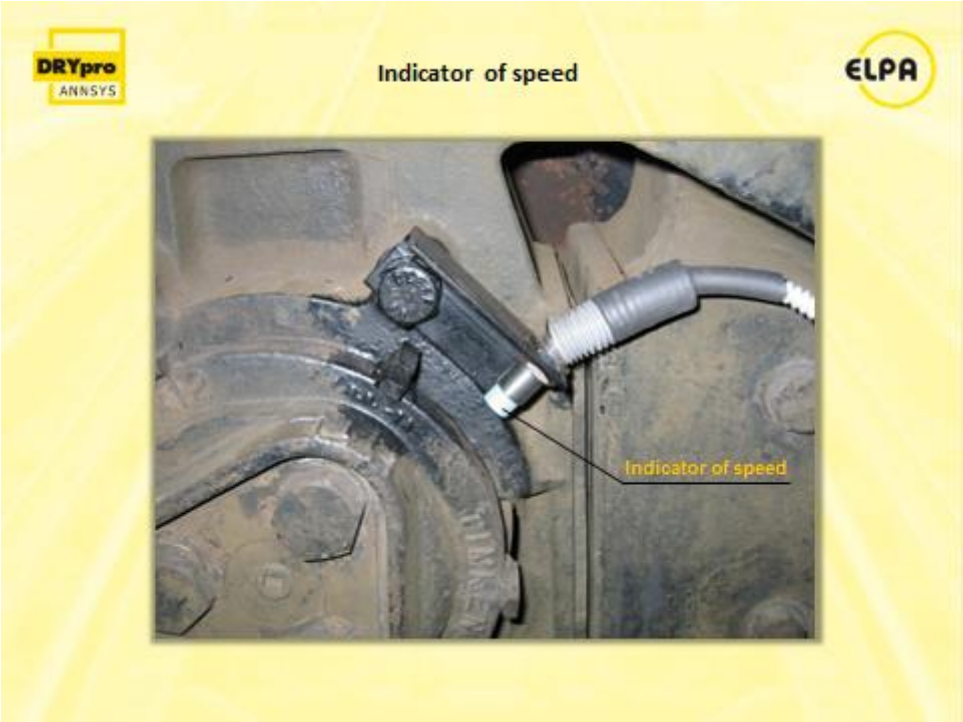
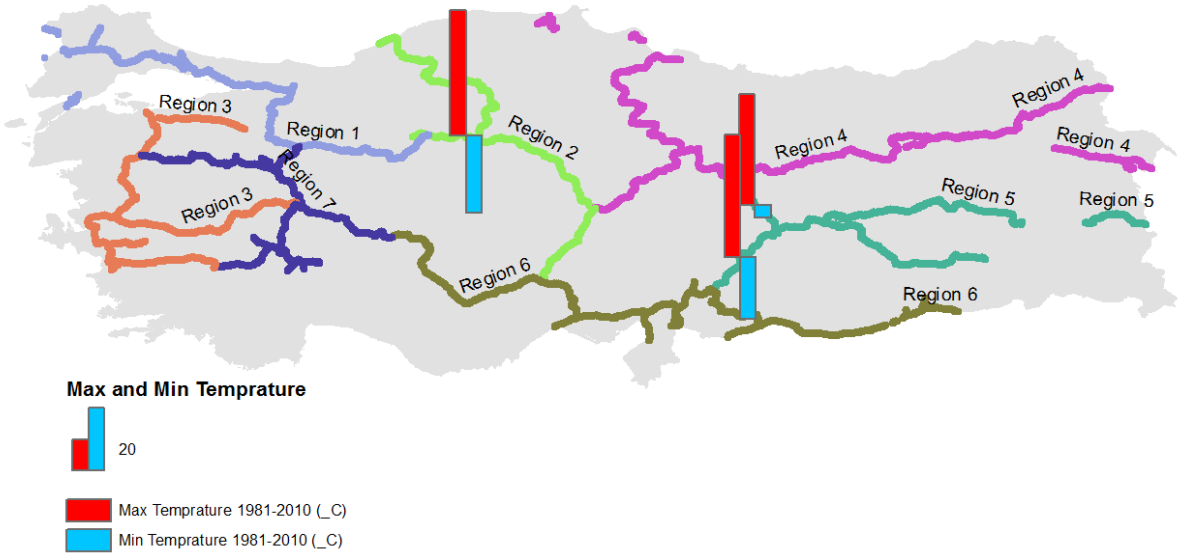

DRYpro
ANNSYS
Indicator of speed
ELPA
Indicator of speed

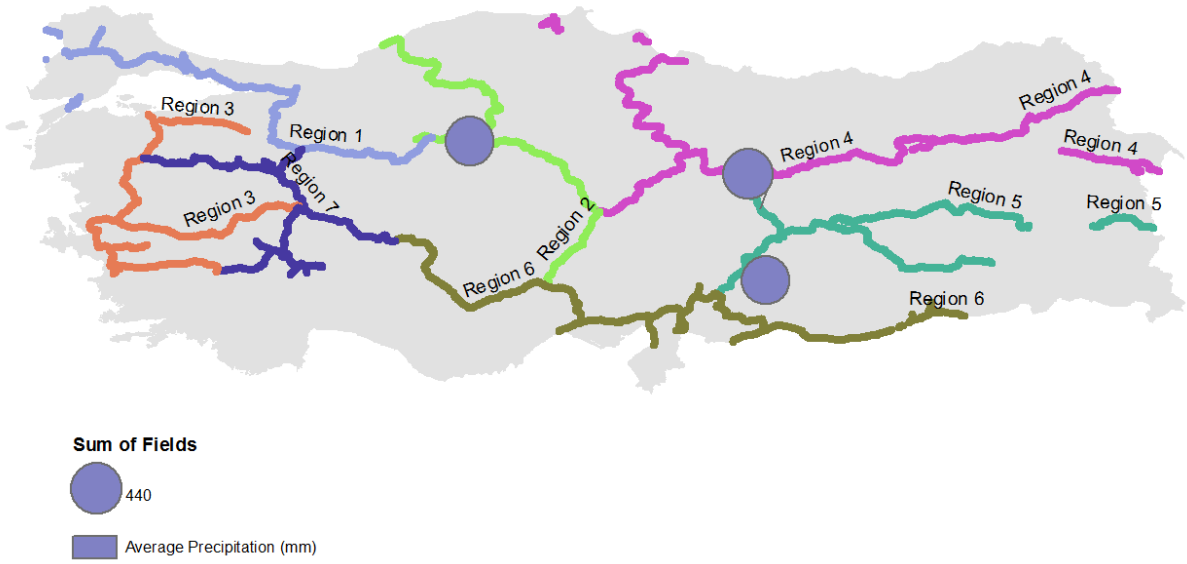
Figure 9 Control module of Elpa On-board lubrication system

13 CLIMATIC DATA

13.1 Climatic Data Of CSL At TCDD's Network

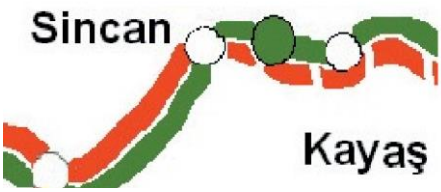
For the three case study lines selected by INTADER, the climatic conditions are as follows;





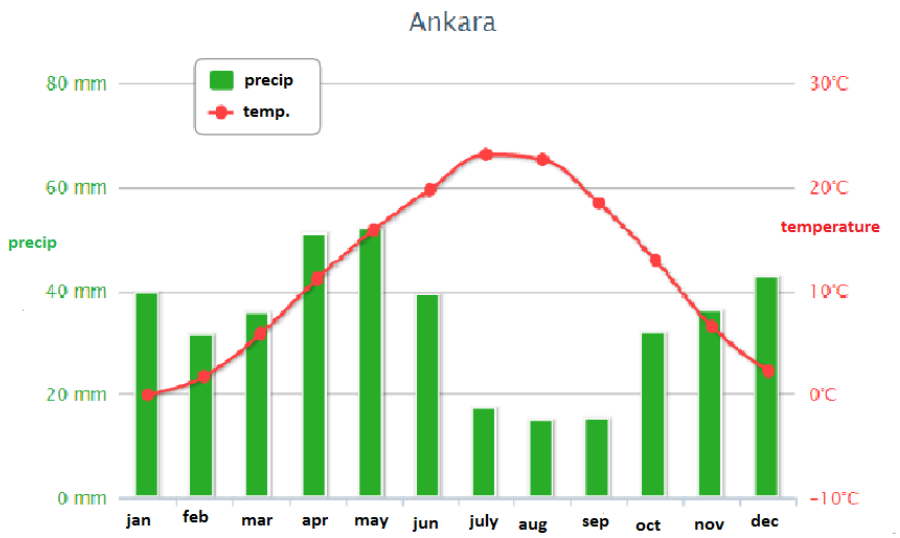
13.1.1 Sincan-Kayaş,

2. REGION



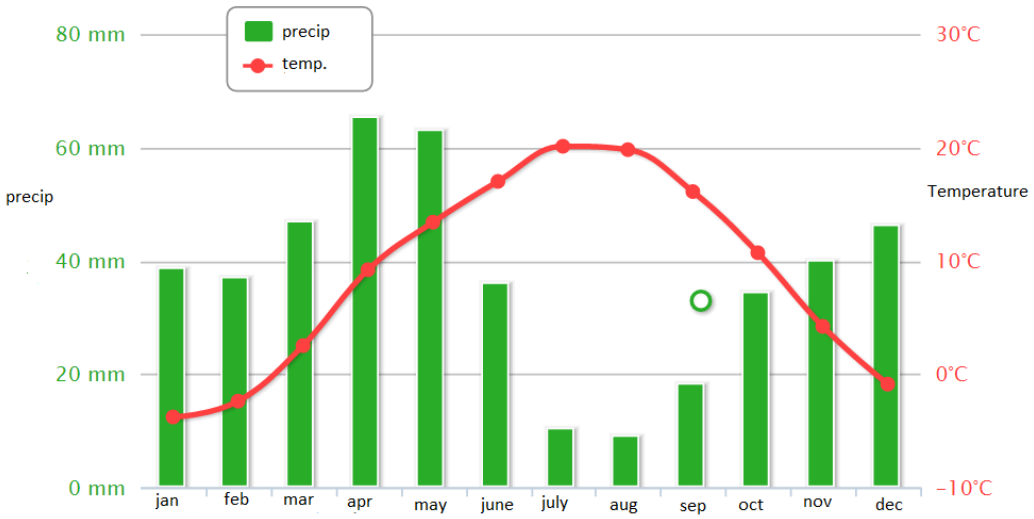
In summer the weather is very cold and dry but the summer season span is very short. The highest temperature is in July and august and the coldest season of the year is in January. In winter, the weather is foggy and it affect the life adversely. The average temperature is 11,7°C and the average precipitation is 389,1mm annually. The highest temperature is 40,8°C and the lowest is -24,9°C. The number of the frosted day is 60-117 and the snowy day is 30,5 annually. The highest elevation of snow is 30cm. Northern winds blow over Sincan-Kayaş line. The strongest winds blow generally in March and April and the highest wind speed seen in Ankara is 29,2 m/sec except of the hurricane seen in 2007 caused a big damage. The average pressure is 913,1 mbar and the highest pressure observed was 935,0mbar but the lowest was 891,0mbar.

Sincan-Kayaş					
Drought Cofficient	1,14		Climatic Type	arid	
rainfall ffectiveness index	23,19		Climatic Type	Semi-humid	
DeMartonne					
Drought Index	10,77		Climatic Type	Between steppe climate- humid	
Trewartha					
Climatic type of Winter season	Cold, (-0,10) Celsius		Climatic Type of Summer Season	warm climate (23,10) celsius	
Thornthwaite					
Climate classification	D1,d,s,b'2	**C1**: Semi-drought	**B'1**: mesothermal climate	**d**: Surplus water at low level or absent in winter	**b'2**: evaporation rate in summer : % 56



13.1.2 Malatya-Divriği,

The Malatya-Divriği line connects two different cities. The origin of the line is Divriği and the destination is Malatya. So there are two different climatic characteristics on the line.



From Divriği To Çetinkaya					
Drought Cofficient	0,90		Climatic Type	Semi-arid	
rainfall ffectiveness index	29,54		Climatic Type	Semi-humid	
DeMartonne					
Drought Index	13,23		Climatic Type	Between steppe climate- humid	
Trewartha					
Climatic type of Winter season	Cold, (-3,80) Celsius		Climatic Type of Summer Season	Mild climate (20,10) celsius	
Thornthwaite					
Climate classification	C1,B'1,s,b'2	**C1**: Semi-drought-subhumid	**B'1**: mesothermal climate	s: Surplus water at medium level in winter	**b'2**: evaporation rate in summer : % 56

From Divriği to Çetinkaya climatic characteristics are like above. This line section is within the boundaries of 4.Region.

This region has a unique climatic characteristic by comparison neighbouring cities. It is located in a micro-climate region regarding the characteristics below,

- Higher above mean sea level than neighbours
- Open to northern winds
- Rugged terrain
- Variable pressure yearly
- It is located on different geographic characteristic regions

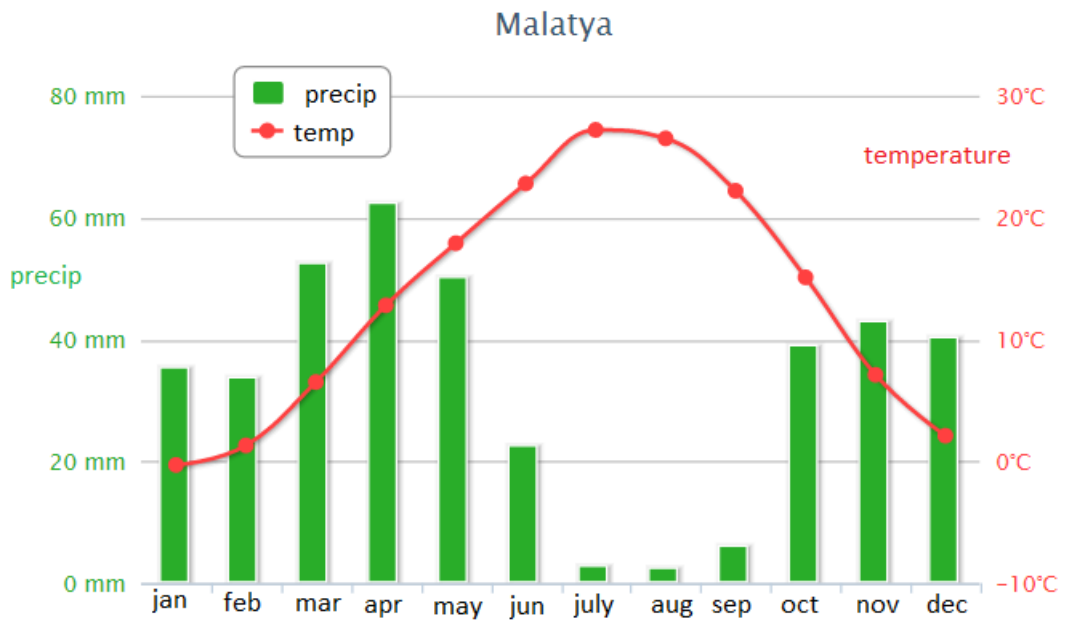
In general, this region has continental climate with some little differences. In summer the weather is very cold and dry but the summer season span is very short. In winter, it is very cold and snowy and the season span is very long.

The coldest city is Anatolia. In winter the weather is cryogenic and the average temperature is 0°C. The coldest time average temperature is -4°C but it is possible to see -36°C. In summer the average temperature is above 19°C but it is also possible to see 38°C. The temperature difference is nearly 74°C yearly. Number of the days when the temperature is below 0°C is 132.

Precipitation is seen in winter, autumn and spring seasons. Annually average precipitation is 420mm.

22% of precipitation is in autumn, 32% is in winter, 36% is in spring and the remain 10% is in summer. The number of rainy day is 105 annually. In the end of the spring and the start of summer hail squall is seen. Number of the days with hail squall is 4 and the number of the snowy day is 30. The average elevation of snow is 20cm.

Average pressure is 653,2 mbar and the lowest pressure is 634mbar. Due to being low-pressure are, this region is open to northern winds. 19,3% of the winds is mistral, 16,8% is northeaster winds and 18,1% is north winds and the remain is various winds.

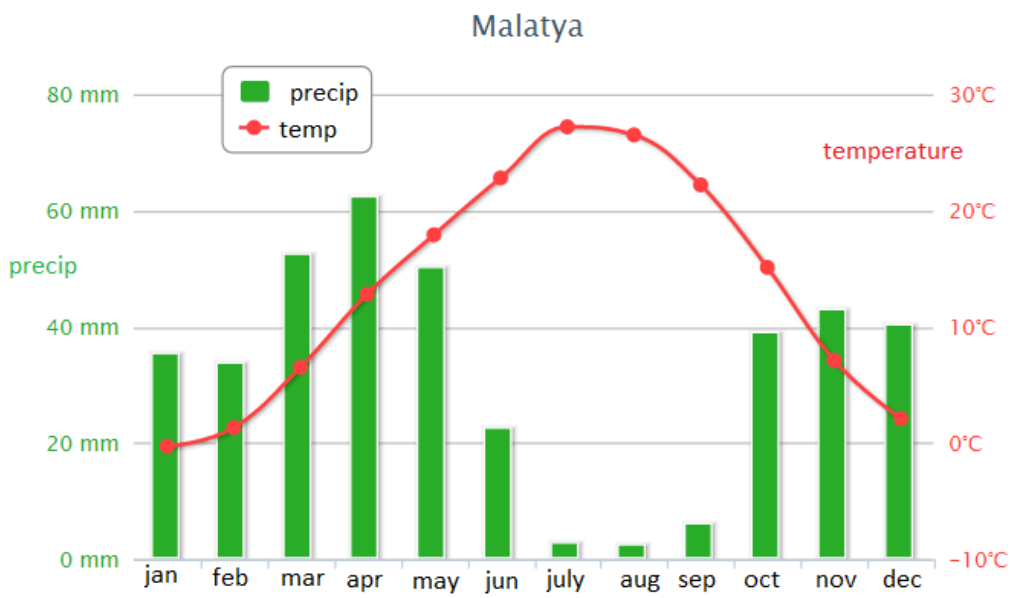


From Çetinkaya To Malatya					
Drought Cofficient	1,36		Climatic Type	Semi-arid	
rainfall ffectiveness index	20,75		Climatic Type	Semi-humid	
DeMartonne					
Drought Index	9,73		Climatic Type	Between steppe climate- humid	
Trewartha					
Climatic type of Winter season	Cold, (-0,30) Celsius		Climatic Type of Summer Season	Mild climate (20,10) celsius	
Thornthwaite					
Climate classification	C1,B'1,s,b'2	**D**: Semi-drought	**B'2**: mesothermal climate	s: Surplus water at medium level in winter	**b'2**: evaporation rate in summer : % 58

In summer the weather is very cold and dry but the summer season span is very short. In winter, it is very cold and snowy and the season span is very long.

130-140 days of the year is sunny and 50-60 days of is partly sunny. The remains are partly cloudy. The temperature is between -20°C and +40°C. From 1920, the lowest temperature seen is -21.1 and the highest is +41°C. The average precipitation is 382,6mm. The highest temperatures are seen in July and august and the lowest temperatures are seen in January and February.

13.1.3 Malatya- İskenderun,



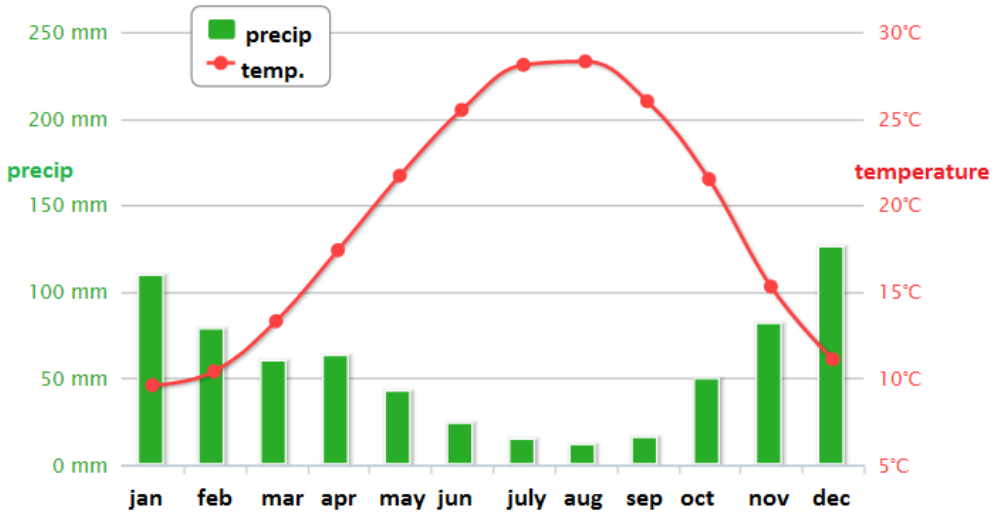
From Malatya to Kahramanmaras					
Drought Cofficient	1,36		Climatic Type	Semi-arid	
rainfall effectiveness index	20,75		Climatic Type	Semi-humid	
DeMartonne					
Drought Index	9,73		Climatic Type	Between steppe climate- humid	
Trewartha					
Climatic type of Winter season	Cold, (-0,30) Celsius		Climatic Type of Summer Season	Mild climate (20,10) celsius	
Thornthwaite					
Climate classification	C1,B'1,s,b'2	**D**: Semi-drought	**B'2**: mesothermal climate	s: Surplus water at medium level in winter	**b'2**: evaporation rate in summer : 58%

Malatya;

In summer the weather is very cold and dry but the summer season span is very short. In winter, it is very cold and snowy and the season span is very long.

130-140 days of the year is sunny and 50-60 days of is partly sunny. The remains are partly cloudy. The temperature is between -20°C and +40°C. From 1920, the lowest temperature seen is -21.1 and the highest is +41°C. The average precipitation is 382,6mm. The highest temperatures are seen in July and august and the lowest temperatures are seen in January and February.

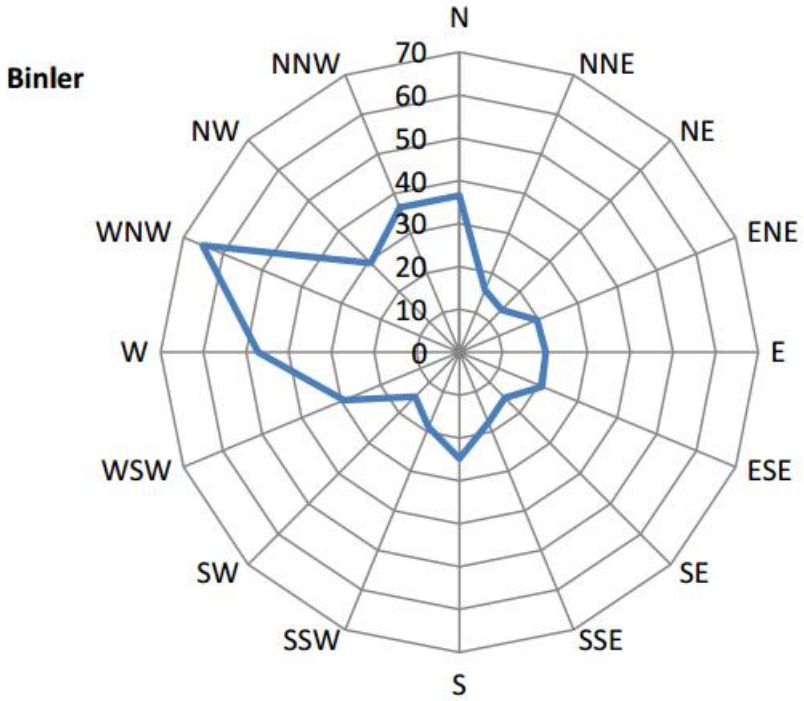
From Kahramanmaraş to Adana					
Drought Cofficient	0,79		Climatic Type	Semi-arid	
rainfall effectiveness index	26,91		Climatic Type	Semi-humid	
DeMartonne					
Drought Index	13,13		Climatic Type	Between steppe climate- humid	
Trewartha					
Climatic type of Winter season	Mild climate		Climatic Type of Summer Season	Very warm (28,10°C)	
Thornthwaite					
Climate classification	C1,B'4,s2,a'	**C1**: Semi-drought- low humid	**B'4**: mesothermal climate	**S2**: Surplus water at high level in winter	**b'2**: evaporation rate in summer : % 42



Kahramanmaraş;

The average temperature is 16,5°C annually. The average temperature in four-month is higher than 23°C so that the climate has mediterranean climate characteristic. Predominant wind direction is West-North-West. The coldest time in Maraş is winter and the lowest degree is -3,7°C.

Direction of the wind is like below,



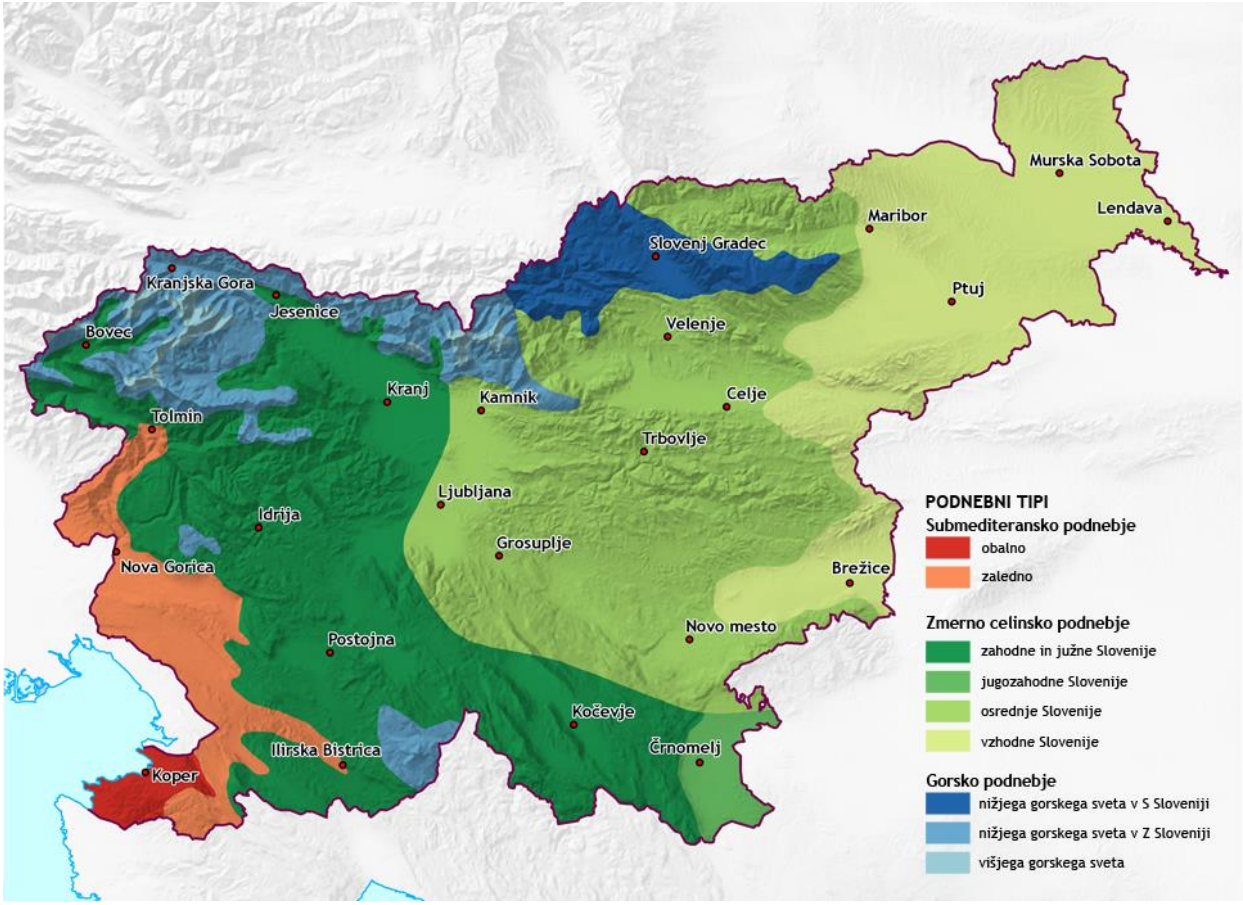
The average pressure is 947,0mbar and the humidity rate is more than 80% in winter. The average humidity rate is 50-60% annually.

Iskenderun;

Climatic characteristic is Mediterranean climate and the average temperature is 32-34°C in summer. And the average of the lowest temperature is 10-12°C. The average of temperature is 18°C annually. Snowfall and frostiness are seen very rarely. The average number of the snowy days is 0,1 annually and the average number of the days when hail squall is seen is 1,5 days. The number of the sunny days is 88,3 and the cloudy is 225,8. The precipitation is highest in winter. The precipitation in winter based on frontal rain. The average precipitation is between 600 and 1000mm. Antecedent precipitation is irregular.

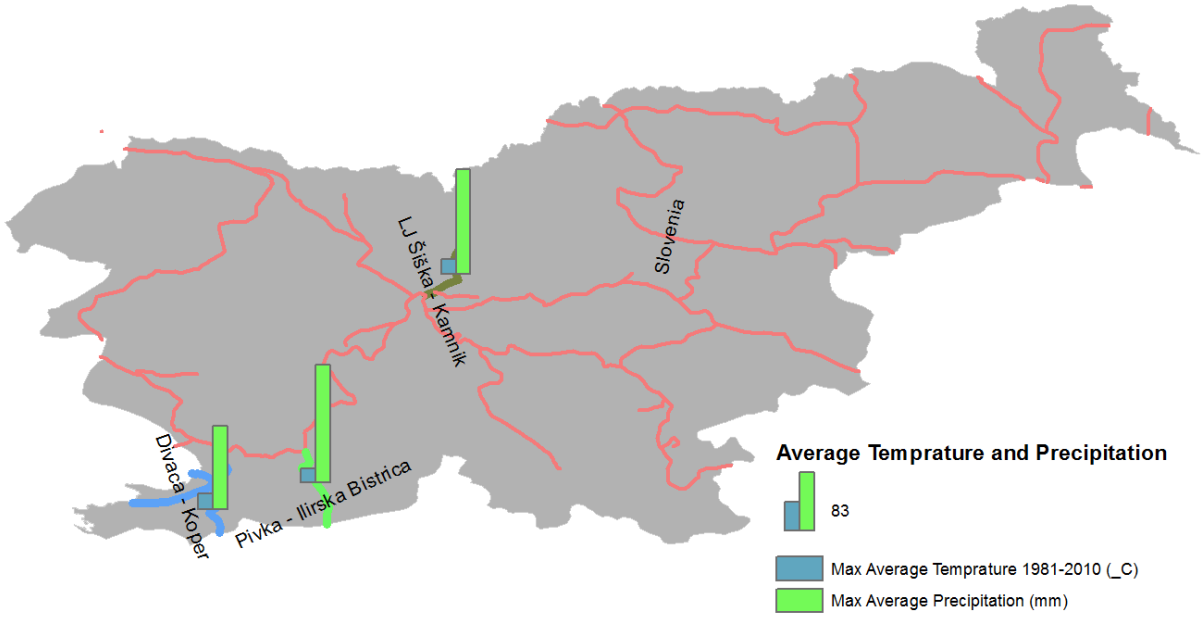
13.2 Climatic Data Of CSL At SZ's Network

For the three case study lines selected by SZ, the climatic conditions are similar to following detailed descriptions of neighbouring measurement locations. The Environmental Agency monitors environmental indicators at specific measuring points.

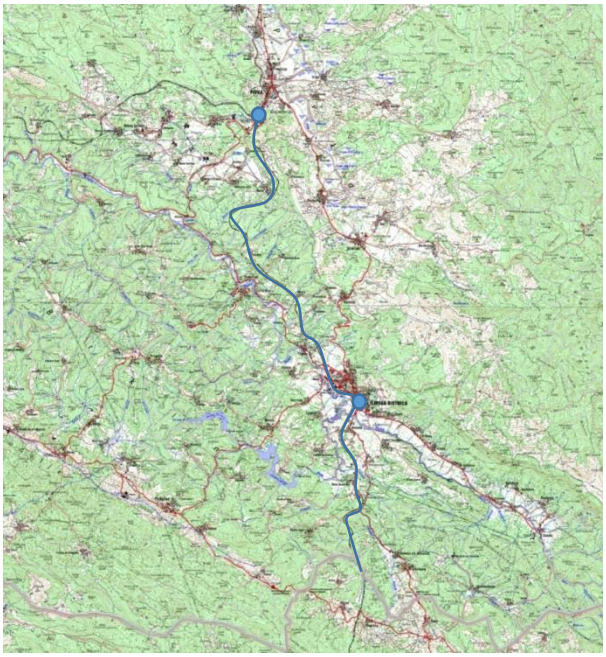


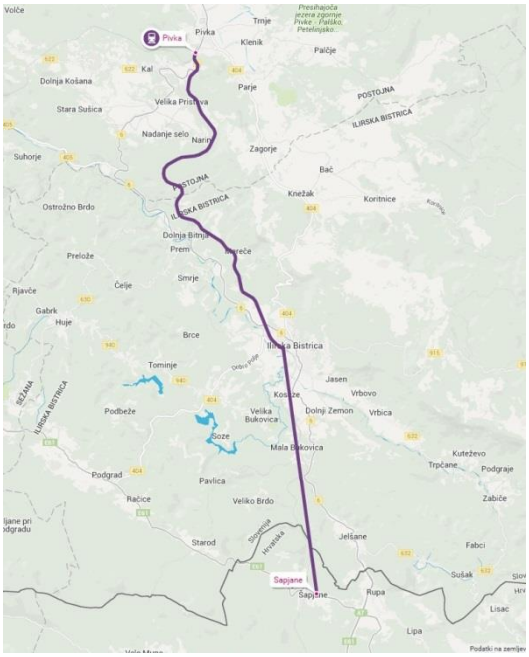
Source: http://www.gis.si/egw/GOS_T12_P04/index.html

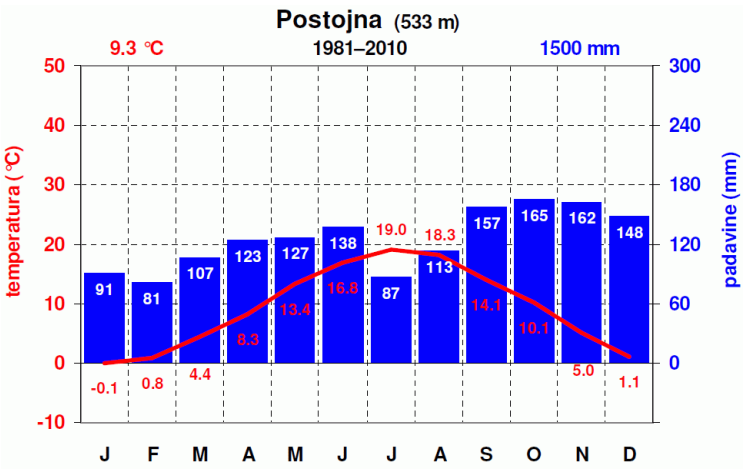
Due to the transfer of Slovenian territory between the Alps, the Dinaric Alps, Mediterranean and Pannonian Basin the Slovenian territory is characterized by a mixture of three types of climate: alpine, Mediterranean and continental. The area of line Ljubljana Šiška-Kamnik Graben has a temperate continental climate. On the area of track Pivka-Ilirska Bistrica-d.m. is temperate continental and sub-Mediterranean hinterland climate. In the area of line Divača-Koper is a coastal sub-Mediterranean climate.

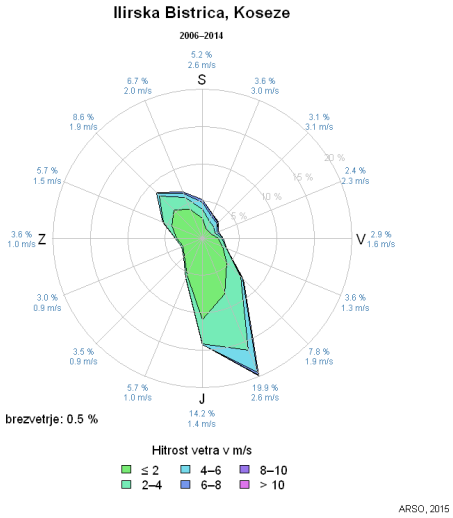


13.2.1 Pivka-Ilirska Bistrica-d.m.

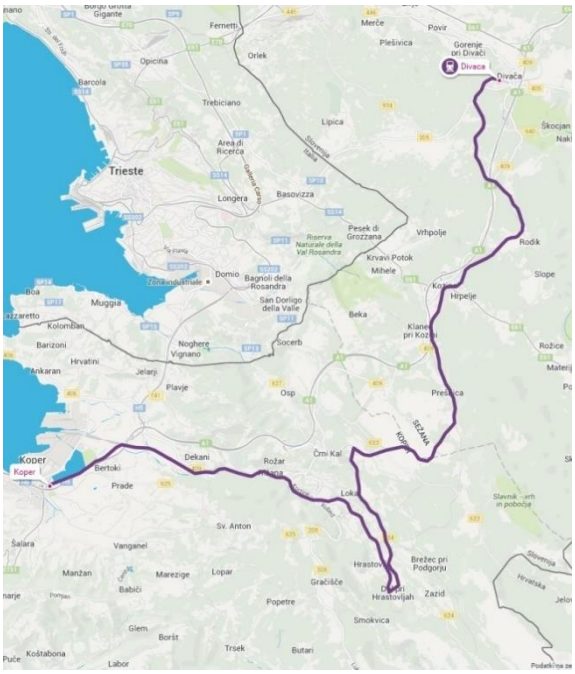


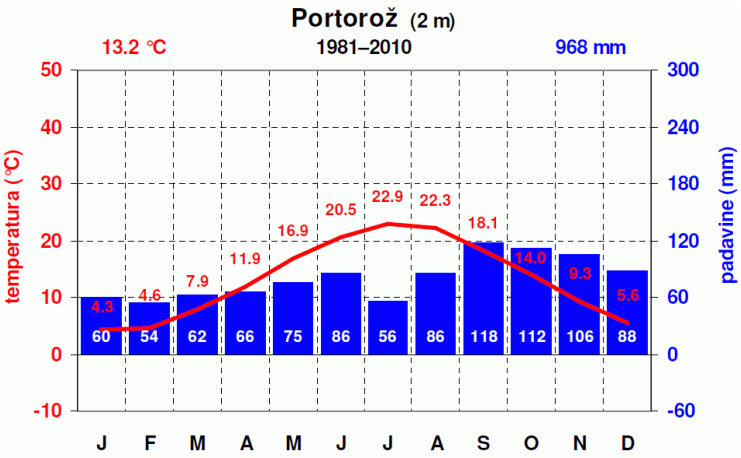


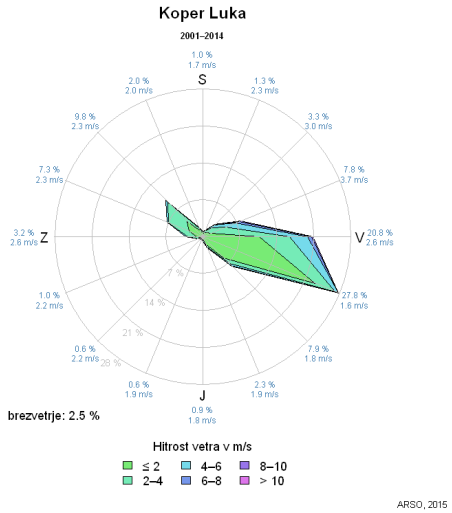




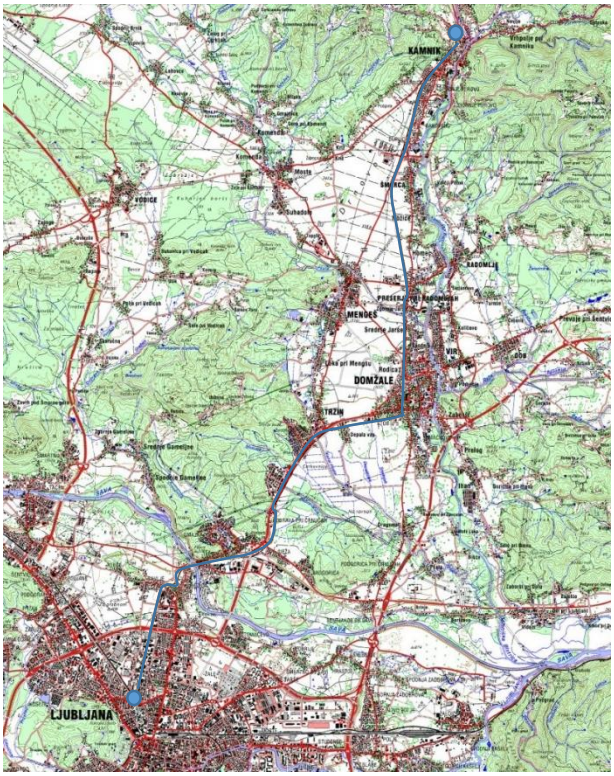
13.2.2 Divača-Koper

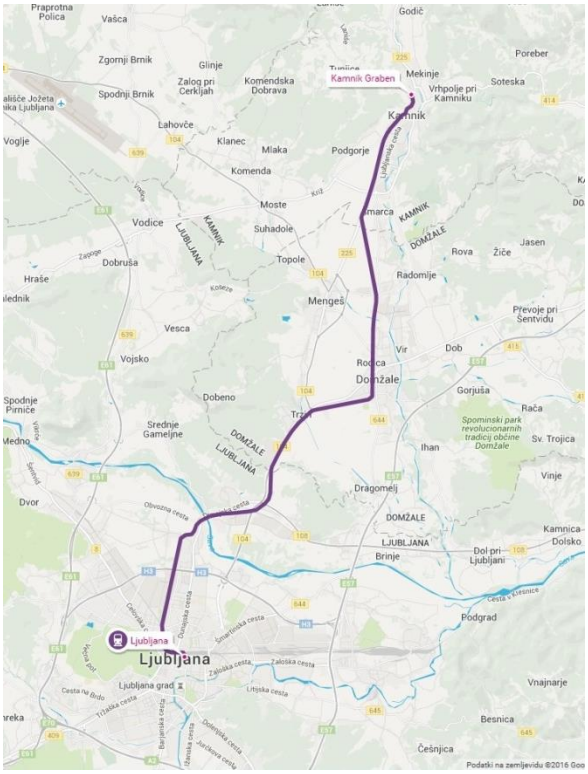


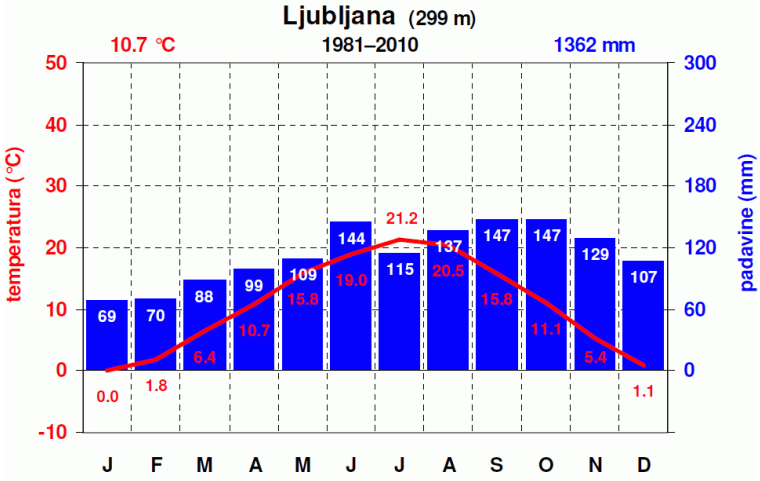


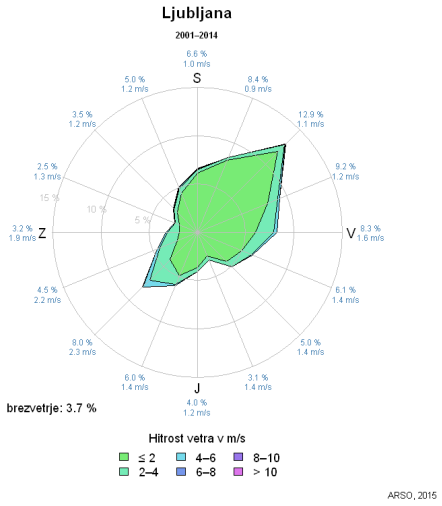


13.2.3 Ljubljana Šiška-Kamnik Graben







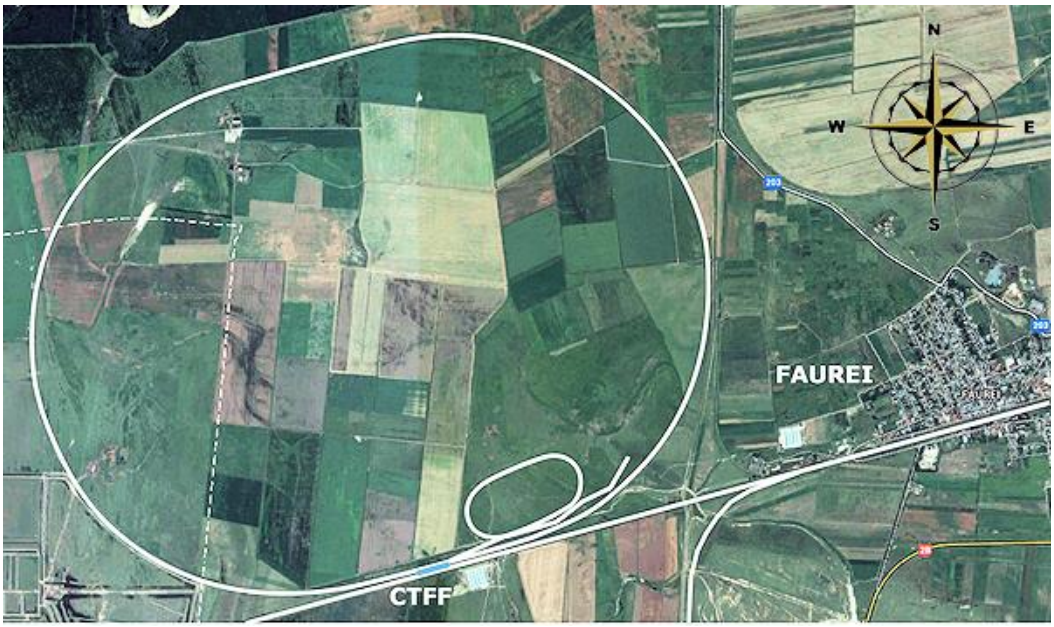


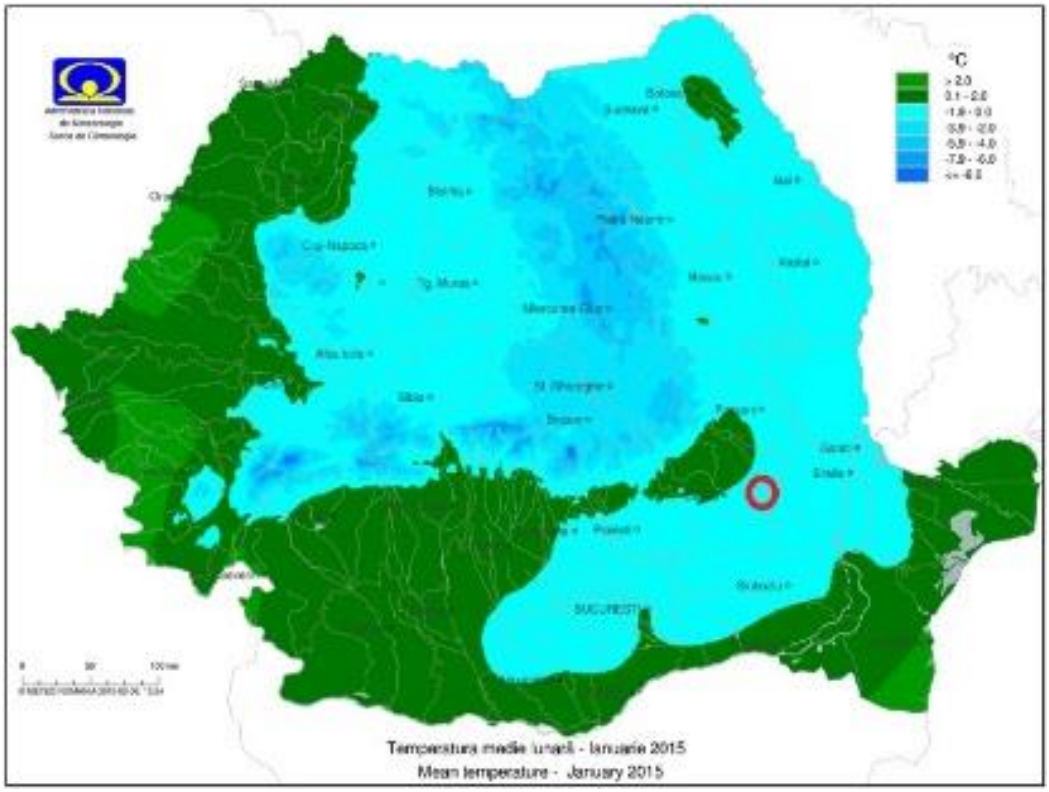
13.3 Climatic Data Of Csl At Romanian Railway Network

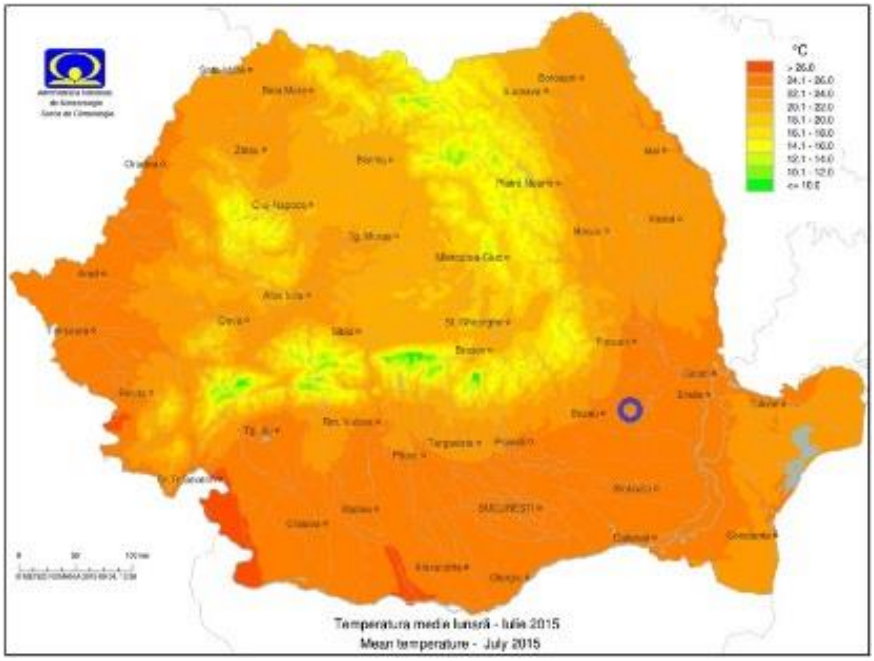
5.3.1. Faurei Testing Ring

In summer the weather is very cold and dry and in winter time, it is very cold, windy and snowy. The mean temperature in last winter/summer representative month (January/July) was (-1,9 – 0,0)^{o} C in winter and 24,1 – 26,0^{o} C in summer (2015 year).

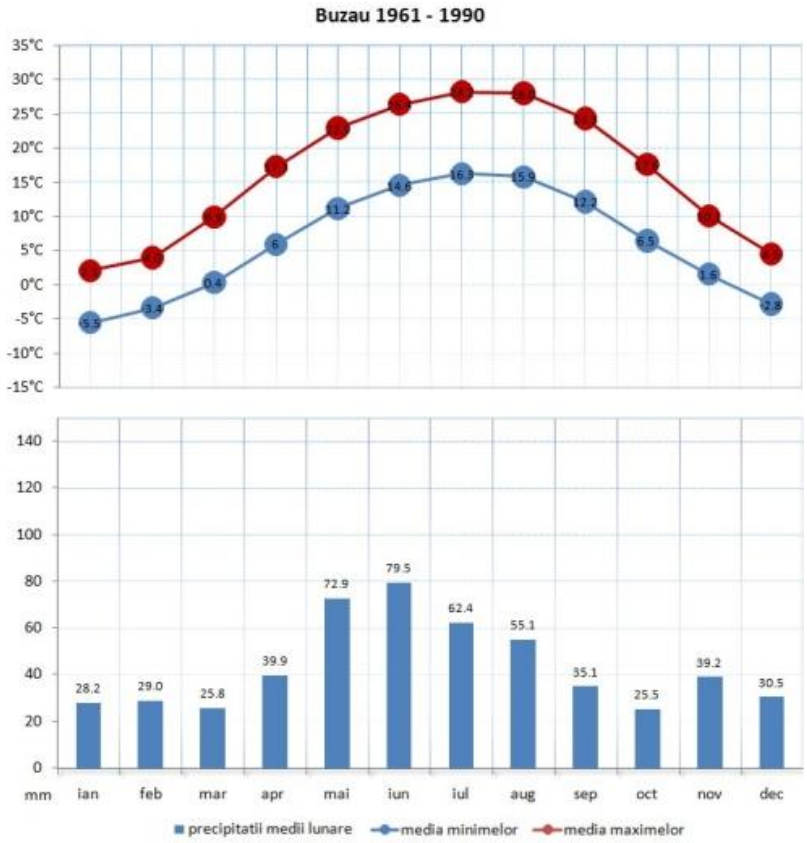
The temperature was measured at metrological station Buzau, near Faurei Testing Ring (30 km between).







The mean value of precipitation at metrological station Buzau between 1961 and 1990 is following:



The data used are available on the Romanian National Meteorological Office website.

14 CONCLUSION

Within this report, the importance of the lubrication of railways has been summarised. Wear has a detrimental effect on rail and wheel life, and adds to maintenance costs. Rail and wheel defects, breaks and derailments cost the rail industry each year due to cancelled and delayed traffic, emergency maintenance, loss of assets, loss of revenue etc. Lubrication is one of the most effective maintenance programs to reduce wear, energy consumption and noise.

Rail and wheel are capital intensive assets for any railway and the adoption of proper maintenance strategies will impact on the life and maintenance cost of these assets. The investment in rail maintenance has a large impact on the reliability, availability, maintainability and safety (RAMS) of rail operations. Increased axle load and longer train length bring challenges in the maintenance of rails and wheels due to increased track deterioration and wear.

For reducing Rolling contact fatigue, flange noise, short wave corrugation, managing friction coefficient periodically can be beneficial. Another aspect of managing friction coefficient can be energy saving and steering performance of trains.

It is already known that lubrication has many significant benefits that are well known by railway professionals. Within this report, it was proven with the real experiences and the results of the studies from IMs. At TCDD, while reducing the rail and bogie wear through lubrication, it is also seen that the fuel consumption reduces 5%-15%. It is also seen that the rail life increased 45% on alignments, 150% on curves, also the wheel life increases 50-55%. From the economic aspect of the benefits of lubrication, after putting lubrication into practice at TCDD, the maintenance department realized that the wheel used to need to be maintained 3 times less. It is also known that RCCF has wear reduction through lubrication up to 50%.

It should be well understood that there are many factors affecting lubrication effectiveness. These are lubricants, traffic direction, performance of lubricator, applicator bars and their locations. Proper application of wayside lubricators also includes appropriate equipment selection, suitable lubricant for the particular operating condition, measurement and management of the lubrication effectiveness, positioning of lubricators, and maintenance. Due to the fact that wayside lubrication is cost effective and easy to operate, it is adopted by many IMs. As mentioned above, effectiveness of lubrication can be affected by many factors such as length of curve, curve radius, tangent track, lubricant properties, type of applicator bars (short and long), use of single pair or double pair bars, applicator bar height from top of rail, application rate, train direction (bi-directional or uni-directional), locomotive truck wheelbase, axle load, speed, track alignment factor, train braking, bogie type, sanding, gradient, wheel–rail profile, rail–wheel temperature, contamination and climate.

There are several characteristics affecting the performance of lubrication. However, it can be said that there are three key characteristics of lubricants that impact performance especially in trackside systems. These characteristics can be defined as lubricity, retentivity and

pumpability. For instance, on TCDD's network, on the demands of TCDD a new lubrication system had been developed in collaboration with a lubrication system manufacturer. The new lubrication system covered the technical requirements. However, it was noticed that the performance of lubricant didn't perform well, and TCDD decided to use a lubricant which works better on TCDD network.
Within this report, types of lubrication; wayside, onboard, hi-rail, types of wayside lubricators; hydraulic, mechanical, electrical were identified. The most appropriate lubricant for onboard lubrication that was recommended by TCDD as a result of the experiences on its own systems were highlighted. Also, a description of friction modifiers was summarized.

Reference Standards For Lubrication Devices And Reference Standards Or Methods (With Target Values) Requested For Lubricants were given.

Since, SZ will perform on site testing to validate different types and methods of lubrications and new eco-friendly lubrication under different climate conditions relevant to Southern Europe, the climatic data of Case study lines of SZ, and TCDD was identified.

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6. WAYSIDE LUBRICATOR PLACEMENT MODEL FOR HEAVY HAUL LINES IN AUSTRALIA **Md. Gyas Uddin 1, 2, Gopinath Chattopadhyay1, 2, Peter Sroba3, Mohammad Rasul1, 2, Alex Howie4**

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8. Tribology of the Wheel – Rail, Contact **,Ulf Olofsson and Roger Lewis**

9. Report on current knowledge of curving noise, Improved Noise Management, **Richard Dwight (UoW), Jiandong Jiang (UoW), Richard Dwight (UoW)**

10. Survey of wheel/rail lubrication practices, Roger Larke, 7th March, 2003

11. BEST PRACTICE IN RAIL CURVE LUBRICATION AND REMOTE PERFORMANCE MONITORING IN HEAVY HAUL LINES, **Gopinath Chattopadhyay1, 2, Md. Gyas Uddin, A. Desai, Peter Sroba, Mohammad Rasul, Alex**

ANNEXES

The annexes to this document include:

ANNEX-1 Description of proprietary flange lubrication systems used by TCDD

ANNEX-2 The results of questions to infrastructure managers regarding lubrication systesm

ANNEX-3 Details of lubrication systems used by SZ

ANNEX-4 Further drawings of lubricators used by TCDD

The contents of these annexes are restricted, for further information please contact the NeTIRail-INFRA project manager, Jon Paragreen (j.paragreen@sheffield.ac.uk).