

# Optimization of railway traffic using software solution

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**Leko, Marko**

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**University of Zagreb**  
**Faculty of Transport and Traffic Sciences**

Marko Leko

**OPTIMIZATION OF RAILWAY TRAFFIC**  
**USING SOFTWARE SOLUTION**

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**OPTIMIZATION OF RAILWAY TRAFFIC**

**USING SOFTWARE SOLUTION**

Supervisors: Assoc. Prof. Borna Abramović, Ph.D.

Student: Marko Leko

Full. Prof. Jörn Pachl, Ph.D.

JMBAG: 0083211566

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Student: **Marko Leko (0083211566)**  
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### Description:

Railway Traffic is one of the most important pillars of passenger and freight transport system. The railway is in the focus of the sustainable development and is the backbone of the traffic and transport development of a region, country and continent on both at the micro and macro levels. The transport system is fully committed towards the market liberalization, so the railways as well as other transport modes are in a need of continual improvement to remain competitive on the liberalised market.

Development of the entire system depends on a set of common aspirations for the development and optimization of individual elements. Most important steps for development of railways are processes for digitalization and automatization of the whole rail sector in order to achieve the maximum utilization of available resources.

Specialized software programs form an integral part for the development of the entire railway system and offer new opportunities for simulating of different variants, planning, construction, testing and optimization of railway traffic system. Rail Sys is one of the basic software enabling all types of testing and simulation in order to find optimal solution for each system. The rail track chosen for the simulation, testing and optimization of the existing condition, by using the Rail Sys software, is Sisak - Sunja - Volinja - Novska.

Mentor:

Committee Chair:

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Associate Professor Borna Abramovic,  
PhD

Full Professor Jörn Pachel, PhD

## OPTIMIZATION OF RAILWAY TRAFFIC USING SOFTWARE SOLUTION

### SUMMARY

The aim of this paper is to optimize the organization of the railway lines between Sisak – Sunja – Novska and Sunja – Volinja. The Optimization of traffic organization is done using the RailSys software tool for traffic management. The idea is to create three infrastructure models which will be the base for three timetables that will be compared in the end. Variant 1 is the recreation of the current infrastructure model with the current timetable, Variant 2 is the creation of a clock-phase timetable with the existing infrastructure and Variant 3 will have upgraded infrastructure with a new signaling system and improved speeds. These variants will be compared, and the results will show how organizational and infrastructural changes affect the capacity of the railway track.

**KEY WORDS:** RailSys; capacity occupation; clock-phase timetable; traffic organization; optimization

This master thesis was done at the Institute of Railway Systems Engineering and Traffic Safety on Technical University Braunschweig (Germany) during the Erasmus+ mobility in summer semester of academic year 2018/2019.

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## **1. Introduction**

The Economy and development of each nation, region and continent depends on strong interconnections between different elements and systems that are part of the modern society. One of the most important parts of each economy is the transport sector, which is used to connect different systems in order to balance the supply and demand of resources and services used for development. The transport sector consists of different modes of transport that are actively participating and competing on the open market. Over time, the transport sector was shaped by new technologies that changed the market in favour of mode of transport that was best at adapting to ever changing situations. In modern times, railway traffic has found its purpose as the backbone of both freight transport and transport passengers in urban areas as well as transport of passengers on distances from 300 to 600 kilometre. [3]

The biggest change of the European market that shaped the rail sector was liberalization of the railway sector. It opened the railway to private companies that could now actively participate on the market. Private companies and private investments significantly developed the sector by putting the customer first. This new approach pushed national rail companies in the direction of necessary changes to stay competitive on the new market. Opening the sector to private companies inevitably brought new ways of thinking in rail business that were oriented towards the optimization of assets, different business and organizational models, that had the effect of better utilization of the railway and higher profits. Other important directions for the development of the sector are processes of automatization and digitalization. These activities are aiming to unleash the potential of computers in all parts of the rail industry through gathering data and knowledge, which are used to enhance productivity, speed, capacity, safety, reduce unnecessary expenditure etc.

Software analysis, as one of the tools for enhancing the rail sector, is an important part of any new railway company that wants to be competitive and offer best business solutions for most of the railway projects. The flexibility of these software solutions offers various possibilities based on real-time data collected from all the stakeholders in the railway. Software analysis offers a wide array of possibilities and brings added value in the form of accuracy, speed, reliability and cost-effective solutions allowing for planning, automatization and utilization of assets. Using the RailSys software tool, the aim of this thesis is to utilize the capacity of the lines and establish the best possible traffic organisation for the development of railway traffic.



The thesis is divided into several chapters that together provide a full explanation of the selected lines and show the effect of each implemented measure that affects the railway network.

The Second chapter describes the methods used for optimizing the organisation of railway traffic. Different methods of optimization including the advantages and the limitations of each method, are described in this chapter.

The third chapter describes the basic tool for optimization of railway traffic in this thesis. The RailSys software, used for creation of simulations and optimization, is described through the three main modules. Infrastructure Manager, Timetable and Simulation Manager and Evaluation Manager are tools that make one whole package for the creation of infrastructure, timetables, simulations and evaluations of results.

Chapter four analyses the current infrastructure which will be used for the process of traffic optimization. The Infrastructure is described through the main railway stations and the general description of lines used for the infrastructure model.

The creation of the infrastructure model, the rolling stock and the timetable is described in chapter five. This chapter describes three variants of the simulation model through timetables, capacity occupation, number of trains and other data that is important for the creation of the model.

A comparative analysis of the three timetable variants is described in chapter six. All three variants of the timetable are compared using the data extracted from the RailSys software. The goal is to determine the best organization and provide solutions for this part of the railway network.

## **2. Methods for the optimization of organization in railway traffic**

Due to the complexity of the railway system and real-time events that can occur, a railway network must have good organization to cope with all possible scenarios. The organization of railway traffic should implement all possible measures in order to optimize the railway network and have the best cost-to-benefit ratio. Several different situations are considered when talking about the organization of a railway system:

- planning of railway infrastructure according to desired service and organization,
- reorganization of traffic on current state of infrastructure using optimization methods, and
- reevaluating the current infrastructure organization and proposing infrastructure modifications.

For each of these situations it is important that all elements of the railway system are well assessed, and that the latest technology is used to provide the best solutions. These activities require the collection of data for the process of development and precious recreation of real-time railway operations.

The optimization of railway traffic is a fundamental part of the development of any railway service due to the utilization of resources, financial reasons and technological advances that affect the fast-changing market and the railway sector. Optimization can have many benefits including faster trains, safer operations, better capacity, lower cost, availability of systems, reliability and many others. Main methods for optimization of railway organization are:

1. analytical methods, and
2. simulation methods.

Both methods have pros and cons and are used according to different requirements and situations concerning railway infrastructure. Methods are described and compared based on all relevant data required and technique of calculation.

## **2.1. Analytical method**

As one of the tools for optimization of railway traffic, the analytical method is used on lines where the traffic pattern does not change and the situation on the line is simple to comprehend. The advantages of this method are that it requires no simulations, which are time consuming (expensive), and can be used anytime regardless of computer availability.

Analytical research can be useful in many low density or otherwise relatively simple situations that might require more time to build and calibrate a simulation than to solve the problem. [1]

Basic requirements for the process of optimization using analytical method are:

- infrastructure data,
- train characteristic, and
- the timetable.

Data is implemented into mathematical formulas for calculation of significant point on waiting time curve and the timetable capacity of the railway line. Due to the lack of simulation tools, these calculations can provide limited results that are valid only for a specific case and cannot be used in case of any changes. Other limitations such as time consumption, the complexity of analysis for nodes and densely populate lines, real time events that can cause situations that require immediate answers and many other are reasons why the railway sector is going in the direction of simulation methods.

## **2.2. Simulation methods**

Simulation methods use computing power to collect and use data, make calculations, predict scenarios and offer solutions. Highly sophisticated software is the backbone of the development and optimization of railway traffic organization and must be based on the latest available data. the Precision of these simulations depends on the invested time and volume of data implemented for development of software models. For replicating realistic situations of railway traffic in simulation, it is necessary to collect and implement huge amounts of data in to the software, which is time-consuming in the short term but can offer a world of opportunities in the long term.

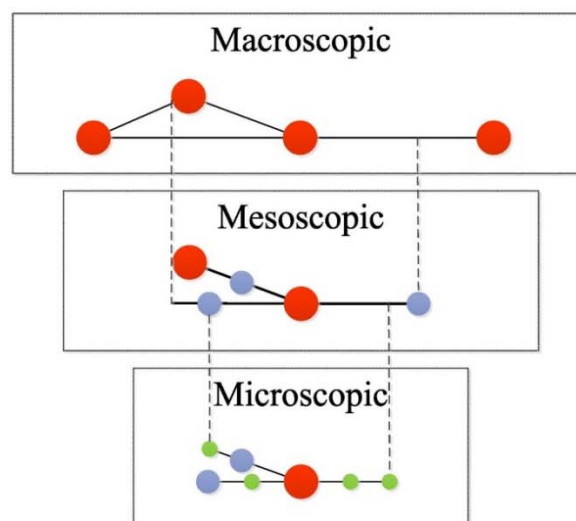
If used properly, simulation methods can provide all kinds of statistical data that offers numerous explicit advantages. The main advantages are unlimited number of simulations that can be run and compared, an adjustable infrastructure model, testing of possible modifications on infrastructure and a number of different solutions. The infrastructure model is stored and is available for testing in case of any changes, which can occur on the macro or the micro level at any point in time. Secondary benefits of this software can go from the development of transport plans for cities, regions and countries, different kind of cost benefit analysis and other effects that are the result of interactions between the railway and other sectors.

The simulation models are divided into three main categories according to:

1. level of details,
2. the analytical approach, and
3. processing techniques.

### 2.2.1. Level of details

Simulation models are based on the level of detail and the volume of data implemented into them as shown on Figure 1. For creation of larger areas and parts of network with basic information, macroscopic models are the best solutions because of the smaller volume of data implemented into the model. These models are designed for macro simulations and research of the whole network but have limitations regarding some precious calculations for specific parts of the network and specific situations.



**Figure 1.** Simulation models based on the level of details  
**Source:** [16]

Microscopic models consist of high levels of detail and data implemented. They are built for smaller sections of the network where we need specific results with high precision and high volume of output for assessments. The big advantage of these models is the realistic approach and results that are contained in the simulation. Due to the high volume of data necessary to create such a model, the limiting factor is the availability of data from all systems that are included in these computer algorithms. When created, a microscopic model can be used by all participants of the railway system for a detailed overview of all the elements that could potentially be evaluated.

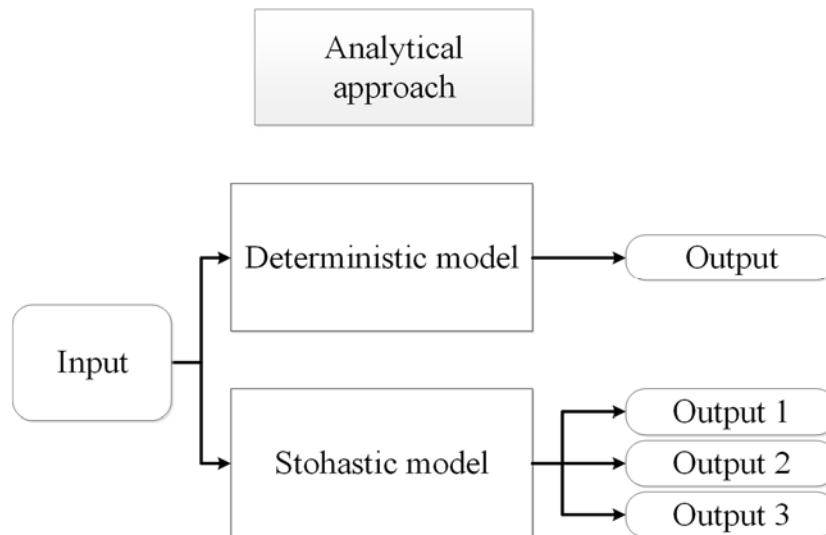
Considering the limitations and the advantages of both macroscopic and microscopic models, a third, “hybrid”, model was developed, and it is called mesoscopic. A mesoscopic model can simulate the same area as a macroscopic using the data from the microscopic model. It could be said that the mesoscopic model combines best of both models to get a better view on a larger area of the network with more details. It optimizes data usage for large simulations for the purpose of better understanding the railway network and results that are more precious.

### **2.2.2. Analytical approach**

There are two ways to separate models according to the analytical approach. Deterministic parameters are fixed parameters with predetermined values. Results of this simulation are always the same and provide exact values for each element. This approach is useful when it is necessary to calculate exact data and have maximal certainty.

Stochastic models are based on probability and statistical data. The parameters of these models are defined by statistical distribution using randomly generated numbers. The main advantage of this model is the assessment of influence of each element on the system and the results are shown in percentages. It is important to assess all elements to have the best picture of the system and assess the direction in which a potential solution should be developed.

The main difference of stochastic and deterministic models is shown on Figure 2. A deterministic model with the same input will provide the same output, but on the other hand, stochastic models, due to the statistical nature, use the same data and provide different outputs. It is clear in this case that deterministic models provide better results, while stochastic models better show the correlation between different elements of the system.



**Figure 2.** Difference of analytical approach for models  
**Source:** [1]

### 2.2.3. Processing techniques

Simulation strategies can differ according to desired results and data availability. There are two main approaches when considering processing technique in simulation tools: asynchronous and synchronous simulation.

Asynchronous simulations are static oriented simulations that work on similar principles as scheduling. Prioritization of trains is fundamental for the development of this kind of model. After the process of prioritization according to various elements, train groups are simulated in phases. Trains with higher priority are simulated first and trains with lower priority are simulated second. The problem with this approach is that during the simulation some train paths are not simulated at the same time. Some train paths that would coincide in real time will not coincide, because the train with lower priority in that case would be postponed. In a nutshell, trains with high priority will always drive according to schedule on the train path and trains with lower priority will be modified to fit in the remaining schedule. This simulation cannot represent realistic situations on the railway network but can be used for scheduling and capacity research.

A synchronous simulation is using one point in time for simulation of all the trains included in the schedule. Trains are dispatched according to the rule of relative prioritization where elements of train speed, rank, point in time, place on the network etc. are included in the simulation algorithm when deciding how to adjust train paths. The Interactions between trains are constant and the result of this is that trains with higher priority have shorter delays. This

means that train paths regardless of train priority could be modified to fit in the schedule. This flexibility of the program is representing real conditions that could occur on the railway network. The best example is when a train of higher priority is faster than the train in front of it. In this case the train behind must slow down to adapt to this newly occurred situation on track.

Considering the complexity of simulating all the parts of system simulations and the volume of output, synchronous simulating of conditions can be a very powerful tool in the hands of an expert. The expert's assignment is to use the collected data to recognize important numbers, which affect the whole system, and analyse possible solutions. Models can be modified and simulated numerous times until a possible problem or solution is detected.

A comparison of two kinds of simulations are shown on Figure 3, where in an asynchronous simulation two trains are cancelled because of intersecting train paths with trains of a higher level, compared to a synchronous simulation where higher-level trains adapt to the new situation on the track. the Result of these adaptations is that some trains will be late to an acceptable extent, but no train will have to be cancelled.

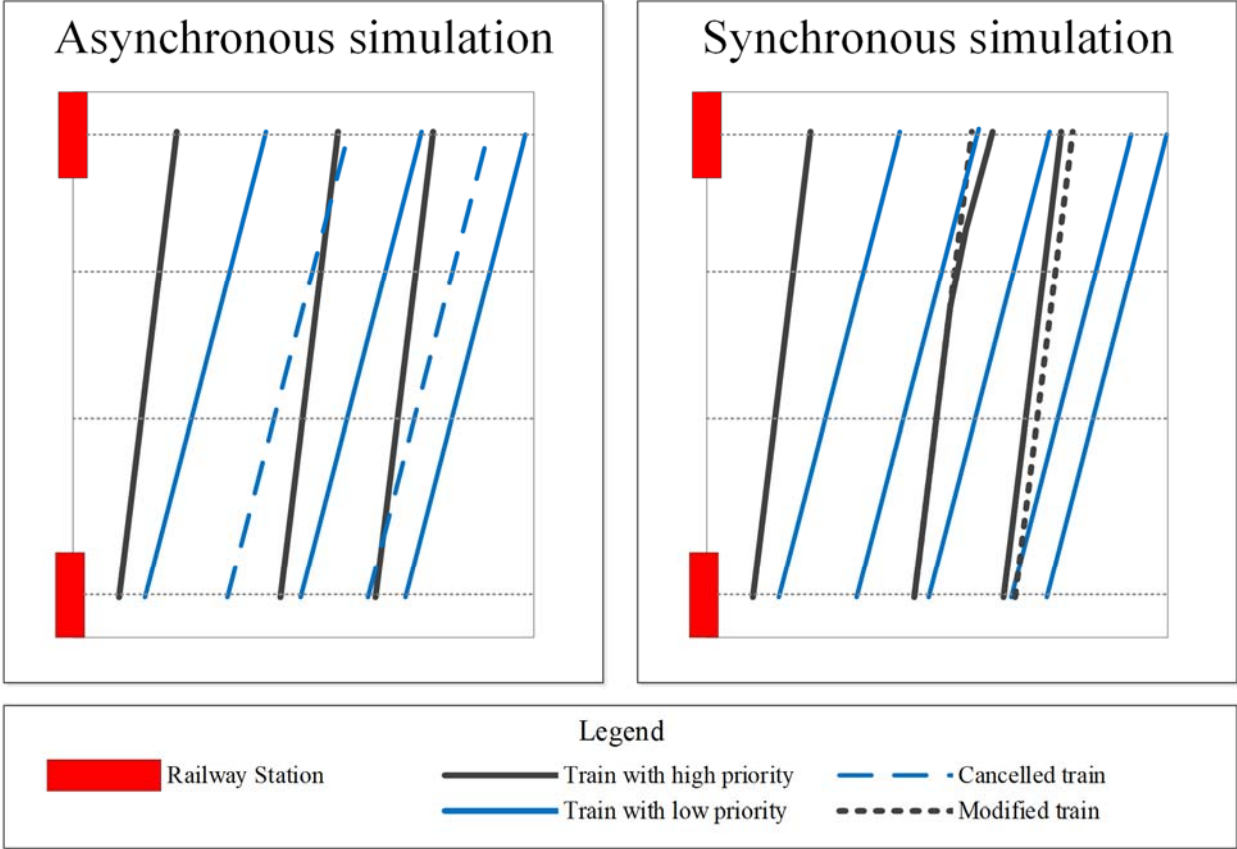


Figure 3. Difference between asynchronous and synchronous simulation  
Source: [1]

### 3. Optimization of railway traffic using the RailSys software

Process of the railway traffic organization is very complex. It consists of several interfacing elements that need to be adjusted continuously during the process. For the optimization of the organization on railway lines between Sisak – Sunja – Novska and Sunja – Volinja, the RailSys software will be used.

RailSys is software developed in Germany for supporting, developing and optimizing the railway system. With its many capabilities, the software can be used to improve systems in many ways. the Main functions of the software are:

- timetable construction, from the local traffic operation to the state railway,
- circulation plan,
- ad-hoc planning of additional train runs,
- construction management,
- creation of work-site timetables in case of line closures,
- infrastructure data management,
- projecting of new railway systems,
- variant studies in case of infrastructure modifications,
- determination of operational quality, and
- determination of running time differences between the conventional signalling systems and ETCS [15]

The software can be used for a variety of situations, from concepts to fully developed lines, covering all parts of a railway system necessary for day-to-day railway operations and all possible events that can occur on railway track. Flexibility, precision and full control during all stages of railway project are advantages that are main reasons why this kind of tool is used worldwide.

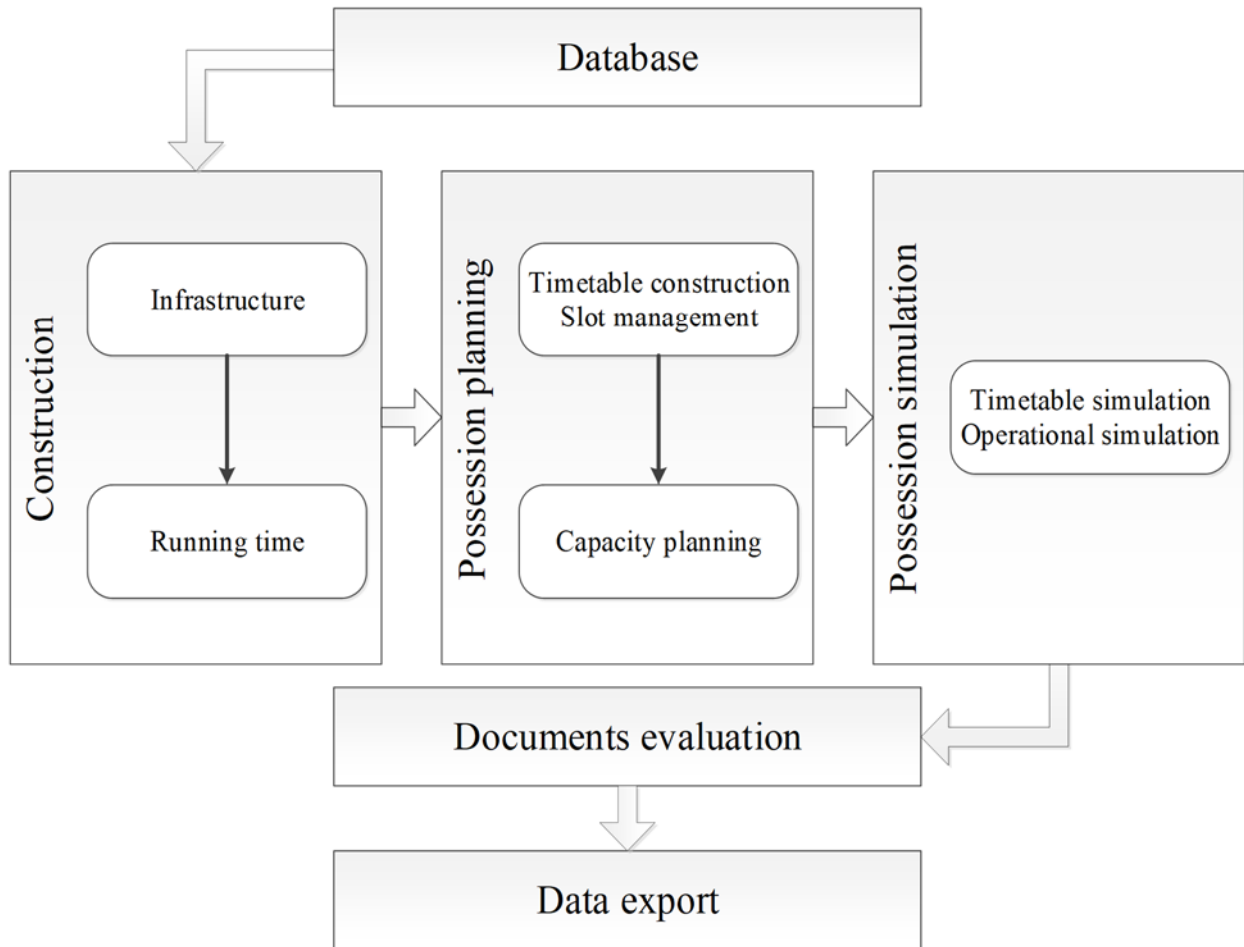
The workflow for RailSys is shown on Figure 4. From a database which includes data for infrastructure, rolling stock, the timetable, operational data and dispatching data and through processes of construction, possession planning and simulating we get wanted results.

Structurally, RailSys is divided into 3 main parts:

1. Infrastructure Manager.



2. Timetable and Simulation Manager, and
3. Evaluation Manager.



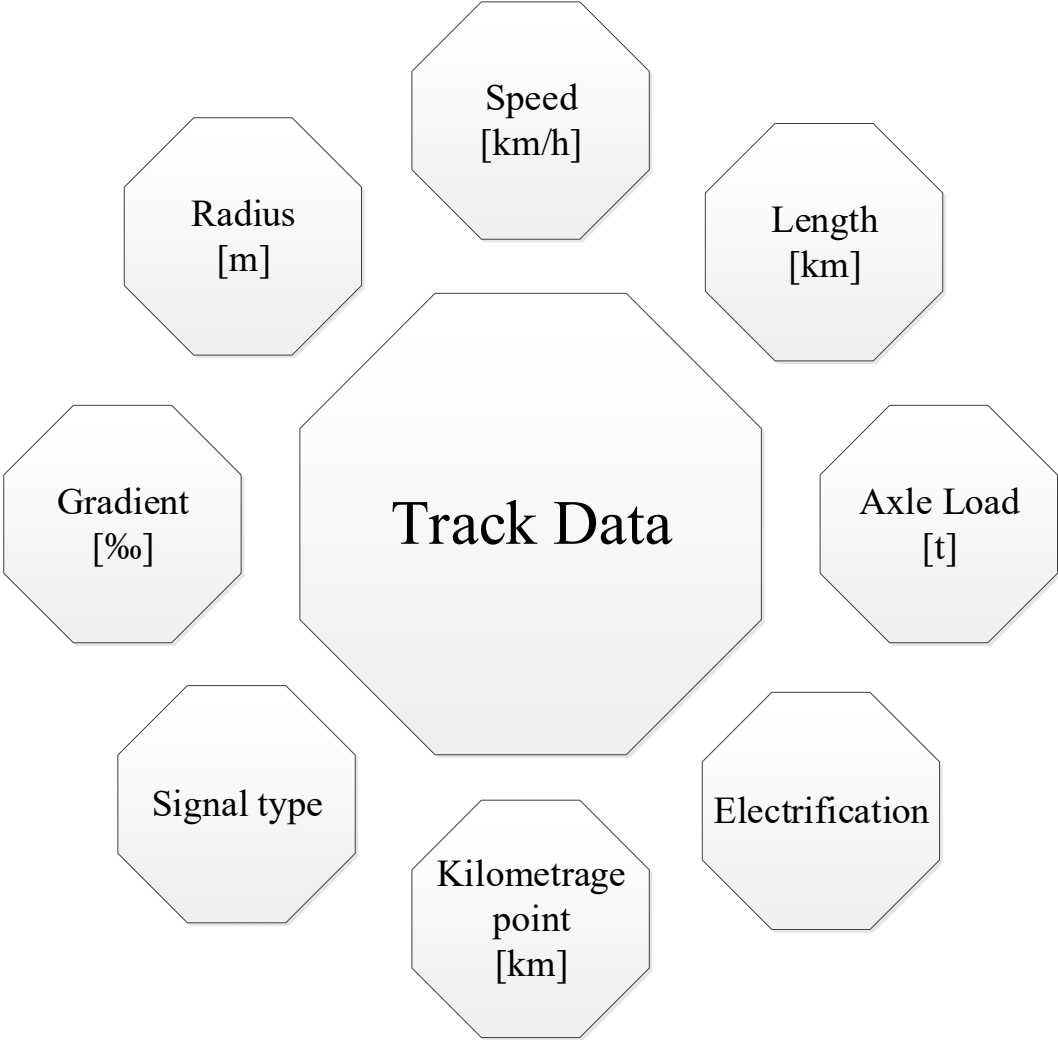
**Figure 4.** Workflow in RailSys  
Source: [15]

### 3.1 Infrastructure Manager

When preparing simulations in RailSys, Infrastructure Manager is the first tool used. Infrastructure Manager is used to create models of railway infrastructure in software and contains all data necessary for functioning. When creating a model in RailSys the basic requirement is to have correct data, which is the foundation for all operations in the later stages of the processes of simulation and evaluation of traffic. Infrastructure Manager contains a vast amount of options, signalling types, level crossing and all components of railway systems that allow for creation of models for any state and variant of railway infrastructure. All data in

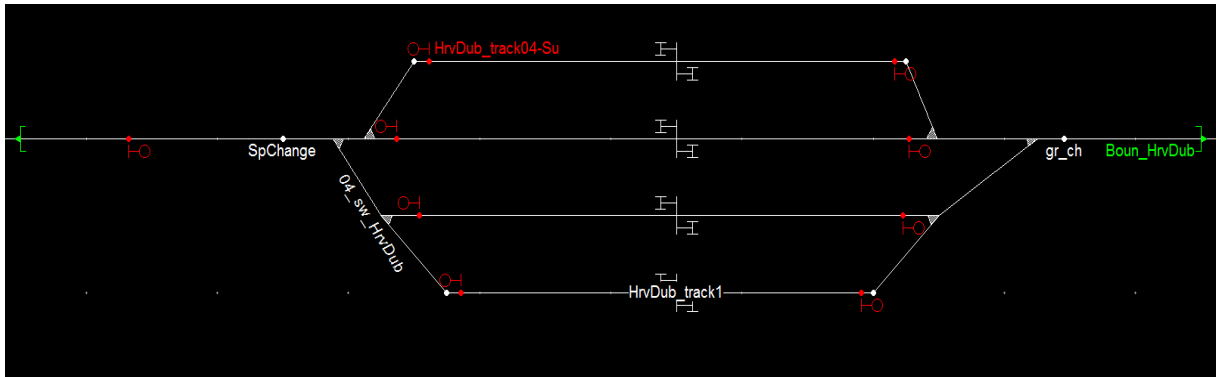
Infrastructure Manager can be modified and should be occasionally verified with the purpose of getting the most precious results during simulation.

Basic data necessary for the creation of a simulation model is shown on Figure 5.



**Figure 5.** Required data for creation of simulation model  
**Source:** [15]

After the implementation of all the data in Infrastructure Manager and the creation of lines, the next step is to create railway stations. Railway stations are created using the aforementioned data and determined by boundaries. Inside every station it is necessary to determine station routes and stopping/timing locations. Stopping/timing locations are used to create block sections, and after all block sections are created, station routes can be created. The creation of station routes is the last step necessary for the functioning of railway stations. An example of a created railway station is shown on Figure 6.



**Figure 6.** Railway station Hrvatska Dubica  
**Source:** [16]

### 3.2 Timetable and Simulation Manager

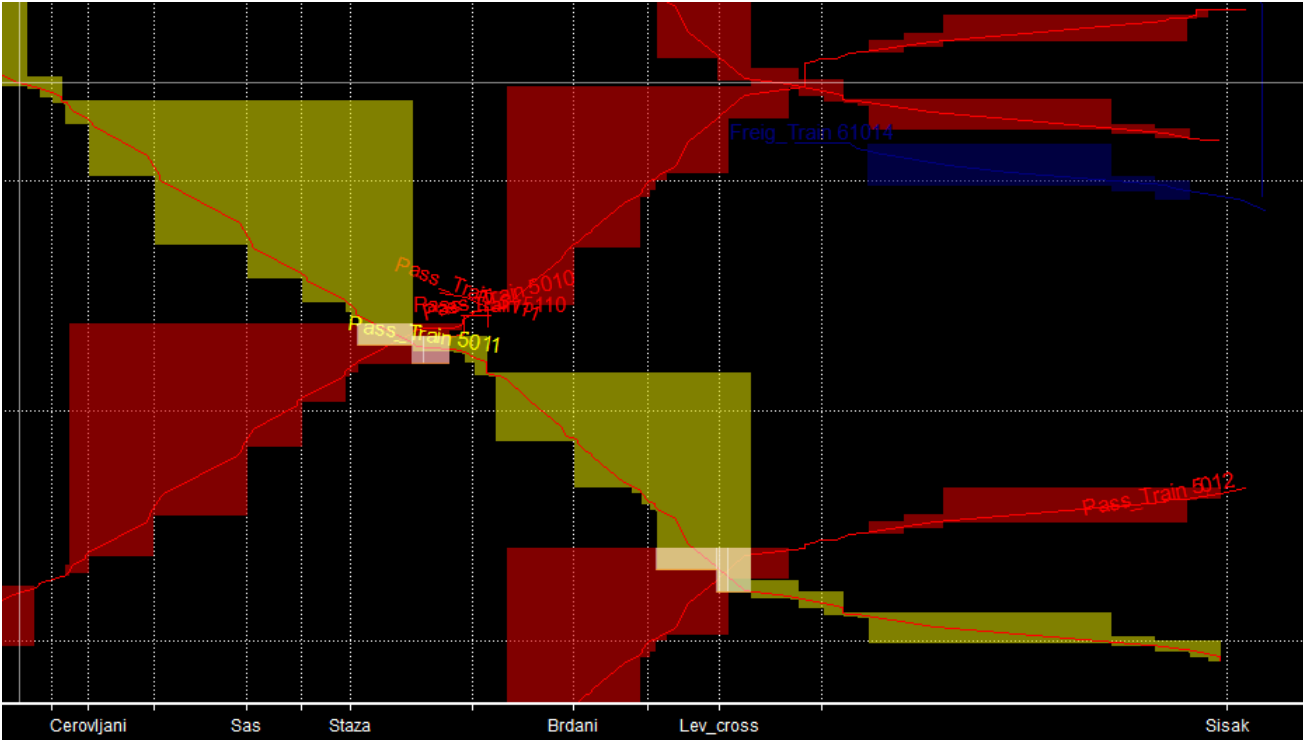
The creation of the timetable is the second phase of project creation and it is created in Timetable and Simulation Manager. The requirements for the creation of a timetable are a prepared infrastructure model without major errors and data necessary to create rolling stock. Timetable and Simulation Manager is the second module of the RailSys software that has several tasks:

- creation of rolling stock,
- creation of timetable, and
- simulation tool

Module is connected to Infrastructure Manger and all changes can be done simultaneously and uploaded in Timetable and Simulation Manager with one click of the mouse button. It contains all possible options for creation of rolling stock and has very good interface that allows for easy modifications in timetable including train routing, departure, arrival and dwell times, conflict detection and other.

On Figure 7 we can see the detection of conflicts in the interface of Timetable and Simulation Manager. This is a very useful tool for easy adjustments of train paths before simulation. Apart from these basic options, Timetable and Simulation Manager has all kinds of options for the creation of a timetable, including days of operation, organization of trains based on different classifications etc. Simulation is also part of this software where, after the creation, a timetable can be tested and checked for any errors. It is possible to create a single or multiple simulation, choose days (or hours) of the simulation etc. the Tool for simulation consists of diverse options

that can be activated during or after the simulation. During the simulation, it is possible to see all occurring events including lateness, routings, failed connections, speeds and all data that affects operations. The simulation is stopped after the time of simulation is finished or if a bottleneck happens. The software includes the possibility to record and export the simulation as a video. The last part of Timetable and Simulation Manager is statistical data that is extracted from the timetable. In the section called “statistic”, it is possible to see all kinds of statistics that reflect the timetable and allow for a detailed overview of all systems and interconnections from track statistic, station statistic, point usage statistic etc. Statistical data is used to evaluate the same timetable from all aspects and determine which results we want to achieve. The best example would be the difference between simulations in which the goal is to determine the capacity of the track and simulations where we want to determine the capacity of the railway stations or some switches. In the Timetable and Simulation Manager it is also possible to determine capacity utilization of the line using the UIC method. This tool uses the UIC method for the compression of the timetable in order to determine capacity. It is only necessary to select which part of the track should be compressed and choose base data for the calculation and the computer does the rest of the work. The calculation of the capacity on different lines and compression of the timetable are used in the later chapters of this thesis.



**Figure 7.** Conflict detection in the Timetable and Simulation Manager  
**Source:** [16]

### 3.3 Evaluation Manager

Results from Timetable and Simulation Manager are evaluated using Evaluation Manager. Evaluation Manager provides results based on previous modules of RailSys that are used as an output which can be evaluated and exported in a different way to provide a precise picture of all systems and elements that affect the simulation. The module has a variety of options for evaluation, including all functions that are significant for railway systems. Systems can be evaluated on several levels, from the evaluation of each train, station, part of the network, node, switch and others. Results are presented and extracted through tables and diagrams. This data is the foundation for the evaluation of the timetable and bottlenecks that could affect railway traffic.

The work in the Evaluation Manager is based on the presentation of potential delay values:

- delays in arrival and departure,
- average delay while staying at the station/stop because of redirection to another track, and
- average delays while staying at the station/stop due to perturbations (additional delays caused in the original simulation of the timetable). [4]

Evaluation Manager will not be used as a tool for the evaluation of the results in this research.

#### 4. The Analysis of the railway connections between Sisak – Sunja, Sunja – Volinja and Sunja – Novska

The Railway lines between Sisak – Novska – Volinja are located in the Croatian region called Sisak - Moslavina County (SMC). The location of the Sisak - Moslavina County in Croatia is shown on Figure 8. With an area of 4.468 square kilometres, SMC is the third largest county in the Republic of Croatia. It takes up 7.9 % of the Croatian territory. The main activities in the county are energetics, oil, metal industry and agriculture. [5]

The population of Sisak-Moslavina County is 172,439 (about 4% of the population of Croatia), while the biggest city in this region, Sisak, has a population of 48,632 (27% of the region's population), according to the data from the Croatian Bureau of Statistics for 2011. The distance between Sisak and the capital city of Croatia, Zagreb, is approximately 60 km. Sisak is part of Zagreb's broader gravitational area and there is potential that these lines could become part of the Zagreb metropolitan area and have great significance for the transport of passengers in day-to-day commuting. [6]

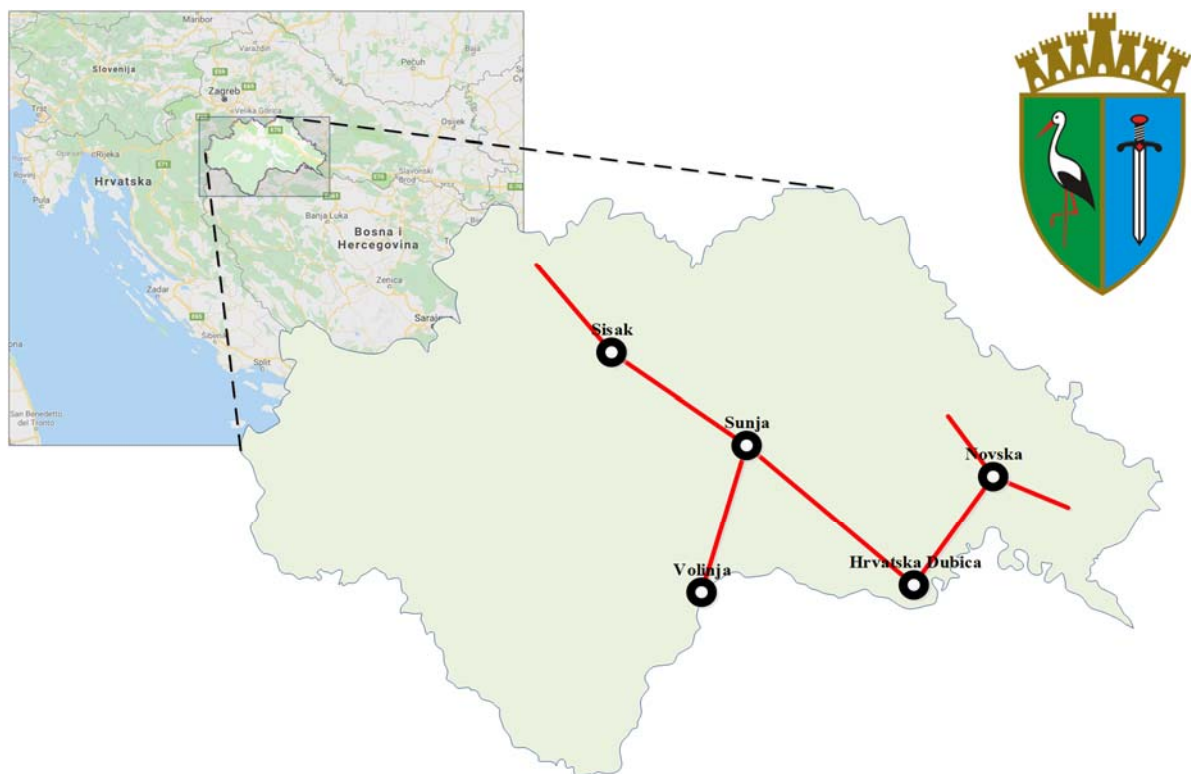
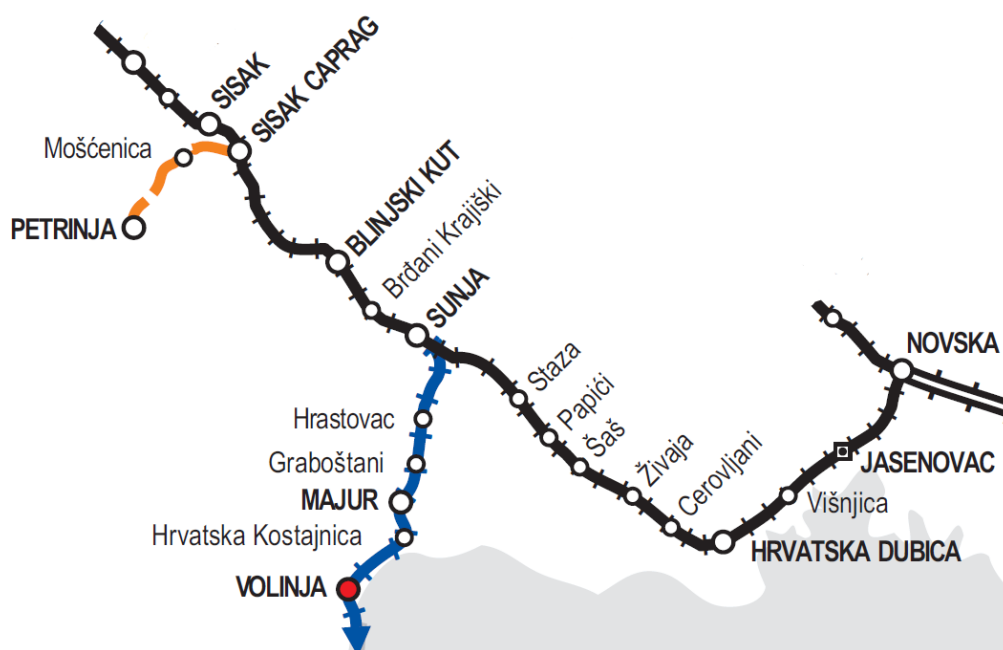


Figure 8. Sisak – Moslavina County  
Source: [18]

Railway lines are used for international and domestic transport of freight and passengers and connect the Zagreb node with the eastern part of Croatia including the freight port of Vukovar (on the Danube river) and goes towards the border with Serbia. The line from Sunja to Volinja goes towards the border with Bosnia and Herzegovina. [7] The entire Croatian railway network is shown in Annex A.

The important railway stations on this part of network are Sisak, Sunja, Novska, and Volinja, which are the bordering stations for development of the simulation model. Figure 9 shows the railway network used for the creation of the simulation model as well as all railway stations and stops included on these lines. All data included in this section was taken from the official documents of HŽ Infrastructure and unfortunately may not be the latest data available due to the time gap between sharing of the information from the field and direction in Zagreb.



**Figure 9.** Part of Croatian railway network  
**Source:** [8]

## 4.1 Railway stations

### 4.1.1. Railway station Sisak

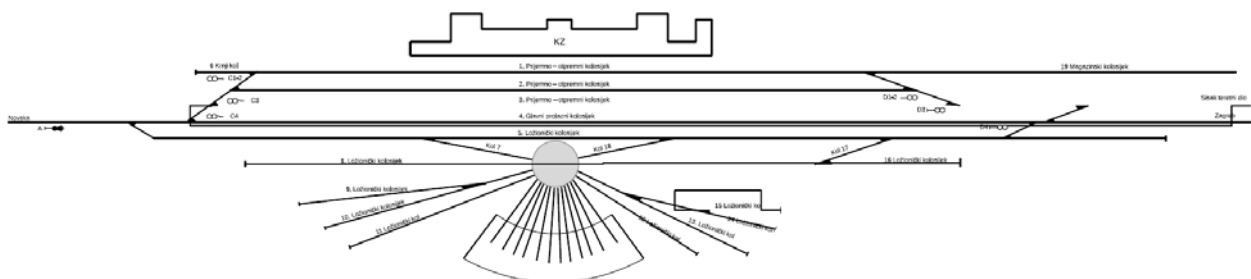
Sisak railway station is located on the 374.489 km of M 502 Zagreb GK – Sisak – Novska railway line. The station is used for the transport of passengers and freight. It is used as a station and is controlling the railway stops of Stupno, TCPR Pračno, Lekenik and Greda station. the

Boundaries of the railway area are on kilometre 373.706 from Sisak Caprag ending in kilometre 373.201 marked by light signals.

The railway station consists of one group of railway tracks for passenger trains and one group of railway tracks for freight trains. The passenger group has 4 main railway tracks used for entry and exit of passenger trains with longest usable length of 392 meter. Freight group has 7 main railway tracks with longest usable length of 943 meter. Railway station Sisak has 3 railway tracks used for industrial purposes.

The interlocking system in Sisak railway station is a relay based electro-relay signalling device “INTEGRA” connected to 1.,2.,3.,4.,5. and 6. station track. The station area is marked with light signals and presignals. All switches that are part of the electro-relay device are remotely controlled.

The automatic phone centre with the call number 854 is used for telecommunication and all phones in the station are connected to this line. The station area of Sisak has UHF radio network as well as a telefax device and interphone devices for internal communication of the station. Sisak railway station is show on Figure 10.



**Figure 10.** Sisak railway station  
**Source:** [8]

#### **4.1.2. Railway station Sisak Caprag**

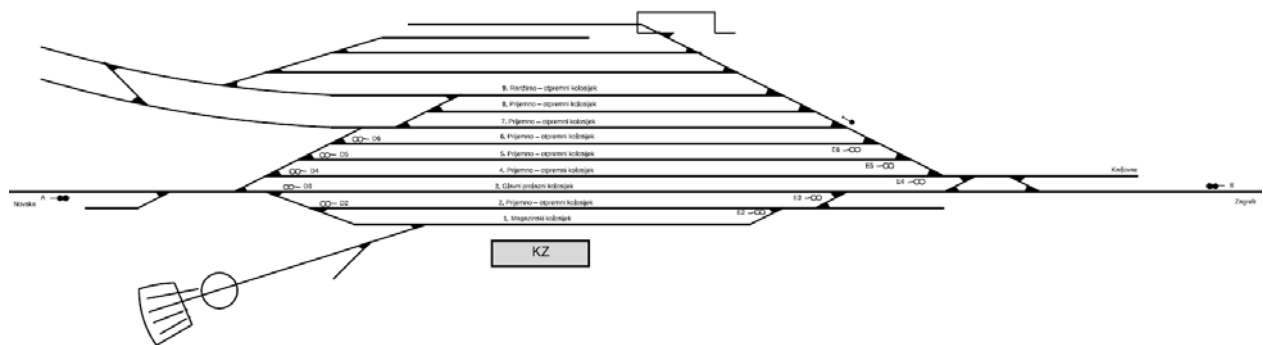
Sisak Caprag is the official railway station located on kilometre 369.966 of Zagreb GK – Sisak – Novska (M 502) railway line. the Station’s function is to handle both passenger and freight trains. Sisak Caprag can be used as a marshalling yard and is marked as a sorting station. It is also used as a branch station for L 210 Sisak Caprag – Karlovac railway line. the Railway area from the Sunja side is located on kilometre 369.174, from the Sisak side in 370.886 km and from the side of Petrinja in 0.917 km.



the Railway area consists of 8 tracks with the longest track of 648 m of usable length. the Railway line towards Petrinja is closed and now used for manoeuvring as shown on Figure 11.

The interlocking system in Sisak railway station is a relay based electro-relay signalling device “INTEGRA” connected to 1.,2.,3.,4.,5. and 6. station track. The station area is marked with light signals and presignals. All switches that are part of the electro-relay device are remotely controlled.

The automatic phone centre with call number 854 is used for telecommunication and all phones in station are connected to this line. the Station area of Sisak has a UHF radio network as well as a telefax device and interphone devices for the internal communication of the station.



**Figure 11.** Sisak Caprag railway station  
Source: [8]

#### 4.1.3. Railway station Sunja

The railway station located on the 351.712 kilometre of the M-104 Novska – Sisak – Zagreb GK line. Sunja is a node station in which railway tracks M 104 (Novska-Zagreb) and R 102 (Sunja – Volinja DG) tracks connect. The main task of Sunja station is to regulate traffic on both lines and day-to-day operations for passenger and freight trains. Sunja controls the railway stops of Šaš, Papići, Staza, Hrastovec, Brđani Krajiški, Živaja, Cerovljani and Višnjica, and additionally it controls Hrvatska Dubica station.

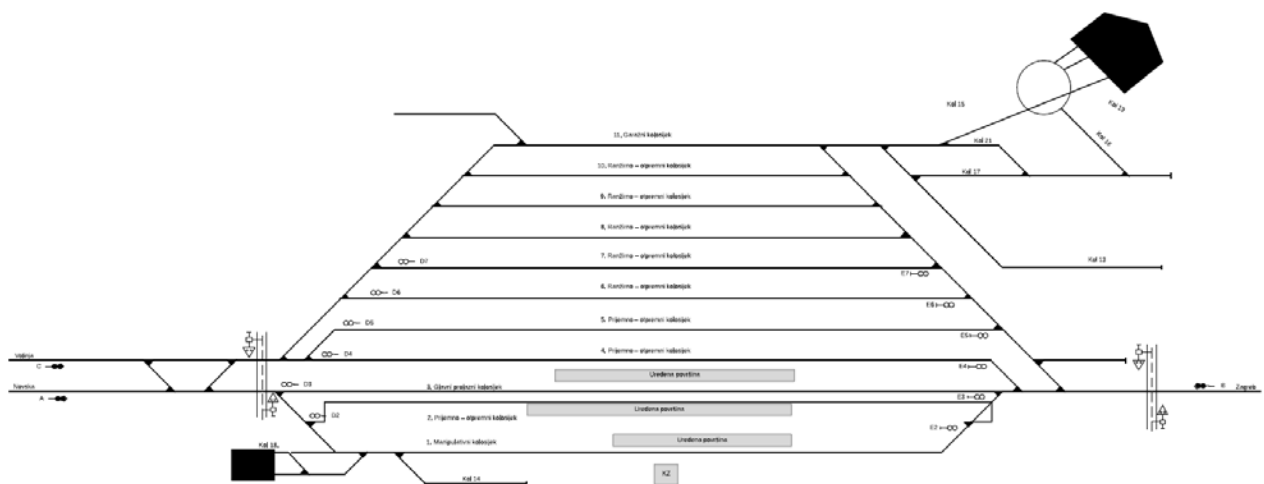
The boundaries of the railway station Sunja are from the east (from Novska) in the 350.600 kilometre, from the south (from Majur) in the 0.929 kilometre and from the west (from Sisak Caprag) in the 352.461 kilometre. The boundaries are marked with fixed red sign tables.

Railway station Sunja consists of 22 railway tracks, 3 of which are used for passenger trains and the rest is used for freight trains and other necessary operations in the railway station.

Railway track number three is the main railway track in the station and is the longest with a length of 711 m. Railway station Sunja is shown on Figure 12.

The interlocking in the railway station is mechanical and all switches must be manually set and locked (“Robel” lock). There are distant signals for the block separation, but these signals do not work.

The telecommunication devices used in station are phone lines and there is a device for the simultaneous taping of communication “MDD500” on both connecting lines. Telefax and portable telecommunication devices are also part of network for communication.



**Figure 12.** Sunja railway station  
**Source:** [8]

#### 4.1.4. Railway station Hrvatska Dubica

Hrvatska Dubica is a railway station located on the 326.000 kilometre of the MG 502 Novska – Sisak – Zagreb GK railway track. Railway station is used for the traffic of passenger trains. Railway station Hrvatska Dubica controls the stop Višnjica which is located to the east in the direction towards Novska.

Boundaries of the railway station are from east (from Novska) in 325.300 kilometre and from west (from Sunja) in 326.685 kilometre.

There are 4 railway tracks in Hrvatska Dubica as shown on Figure 13. 3 of which are used for passenger traffic. Track number 1 is currently closed for traffic. Track 4 and track 3 are the longest and have a length of 647 meters.

Railway station Hrvatska Dubica is secured with a mechanical interlocking system. This system uses fixed visual signs “Stop” and “Slow” to give information to the train driver on how to behave in which part of station. the Station has six switches and all switches are secured with a “Robel” lock previously mentioned for Sunja railway station. Regarding telecommunication, Hrvatska Dubica has four phones that are used for communication and train regulation with Novska and Sunja.



**Figure 13.** Hrvatska Dubica railway station  
**Source:** [8]

#### 4.1.5. Railway station Novska

Railway station Novska is a station with several important tasks located on the 307.004th kilometre of the railway line used for the international transport of passengers and freight Dobova SB – Zagreb GK – Novska – Vinkovci – Tovarnik SB. Novska is used as a railway station for connecting two lines and as a station where two single track railway lines are connected in a double track railway line going towards Vinkovci and the national border with Serbia. Novska is responsible for the traffic regulation through stops Stara Subocka and Jasenovac.

the Boundaries of the railway station Novska are located in the south towards Hrvatska Dubica in 307.476 kilometre, in the west towards Lipovljani at 0.684 kilometre and in the east towards Okučani at 305.554 kilometre.

the Railway tracks in Novska are divided into a group of railway tracks for passenger trains and a group of tracks for freight trains. Railway tracks from number 2 to number 6 are used for passenger traffic and tracks from number 6 to number 18 are used for freight trains. All railway tracks in station are shown on Figure 14.

the Interlocking system installed in railway station Novska is Sp DrL 30 “Lorenz”. This is an electro-relay device and it is installed to secure track 2,3,4,5,6,7,8 and the exit of trains from Novska towards Lipovljani and Sisak, which includes tracks from 9 to 18.

the Telecommunication system in Novska consists of seven phones, fixed and portable UHF devices and telefax.

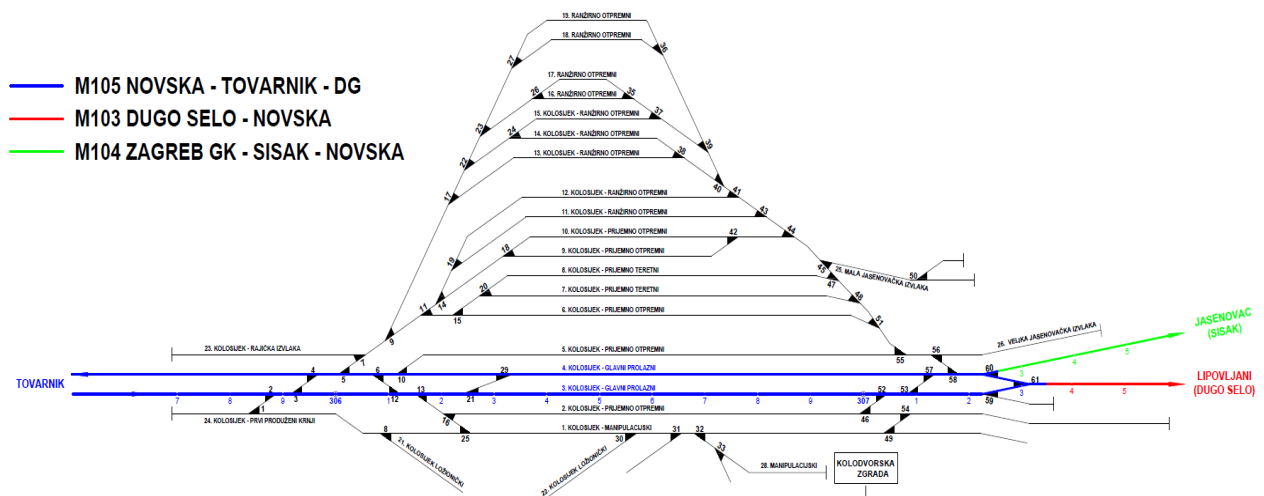


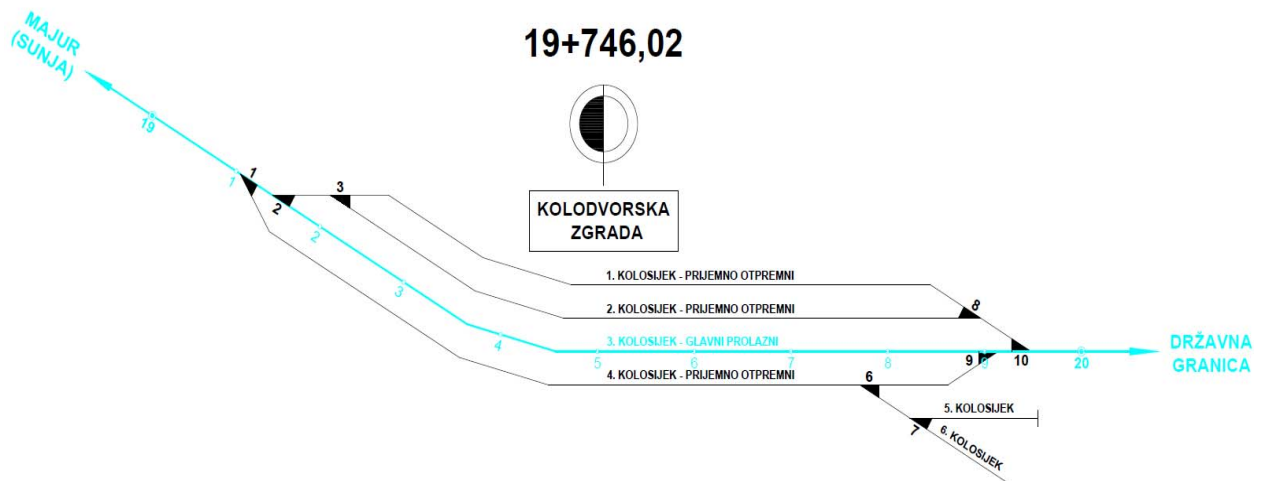
Figure 14. Novska railway station  
Source: [8]

#### 4.1.6. Railway station Volinja

Volinja is a railway station located on the 19.746 kilometre and used as a bordering station between Railways of Croatia and Railways of the Serbian Republic. the Distance to the border between the two countries and the railway station is 1532 meters. the Station is used for passenger and freight traffic and all activities necessary for the traffic of trains between the two countries.

the Boundaries of the railway station are from the north towards Majur railway station in 18.843 kilometre and from the south side towards national border in 20.525 kilometre. Volinja consists of 4 tracks used for freight and passenger traffic and 2 tracks used for industry. the Longest track in railway station is track number 4 with a length of 725 meters. Volinja Station is shown on Figure 15.

Volinja is equipped with fixed table signs “Stop” and “Slow” and traffic regulation is based on non-signalled train operations. the Interlocking system for the switches are mechanical locks “Robel” which must be set and locked manually on site. Telecommunication in Volinja is established using phones, portable devices and telefax.



**Figure 15.** Volinja railway station  
**Source:** [8]

## 4.2 Sisak – Sunja - Novska railway line

Railway track M 502 between Zagreb and Novska is a line that connects the Eastern part of Croatia with the cities in the North-West. The part of this track between Sisak and Novska is 67.489 kilometres long. It is a single-track line, which converts to a double track line starting at Novska towards Vinkovci.

The whole line from Sisak to Novska is electrified and classified as D4 group with permitted load of 22.5 tons per axle and 8 tons per meter of length. Train traffic on this line is regulated partially in automatic block sections and mostly by non-signalled train operations. Block sections are implemented between Sisak and Sisak Caprag allowing for more trains to travel simultaneously between two stations. From Sisak Caprag to Novska train operations are regulated using non-signalled train operations. Please refer to Annex A for figures with permissible load and traffic regulation on this part of the rail network.

The highest speed allowed on this line is 60 km/h and it is predominantly on the eastern part of line between Sunja and Novska. The line has several curves and the lowest curve radius is 286 meters. The biggest gradient on the line is 8.122 ‰. It consists of five railway stations including Sisak, Sisak Caprag, Blinjski Kut, Sunja, Hrvatska Dubica, Novska and 8 railway stops including Brđani Krajiški, Staza, Papići, Šaš, Živaja, Cerovljani, Višnjica and Jasenovac.

### **4.3 Sunja – Volinja railway line**

The Sunja – Volinja – National Border Railway track connects Croatia with Bosnia and Herzegovina and it is called R 102. The length of the line from the beginning in Sunja to the national border is 21.575 kilometres. The whole line is single track.

Track R 102 is fully electrified and is classified as D4 with permitted load of 22.5 tons per axle and 8 tons per meter of length. Train operations on the line are regulated using non-signalled train operations. Permissible axle loads and traffic regulation on the lines is shown in Annex A.

The highest speed allowed for the line is 60 km/h on the bigger part of the line. The lowest curve radius is 235 meter and the biggest gradient on this line is 19.3 %. Sunja, Majur and Volinja are the three railway stations on this line and there are several railway stops including Hrastovec, Graboštani and Hrvatska Kostajnica.

## 5. Optimization of the organization of the line between Sisak – Sunja, Sunja – Volinja, and Sunja - Novska

the Process of the optimization of organization is divided into several steps. the Optimization of traffic organization is produced from the creation of several models of infrastructure, timetables and the comparative analysis of data from the RailSys software. There are 3 variants of the models compared:

- variant 1 is based on the current infrastructure and timetable and simulates train traffic in reality,
- variant 2 implements a clock-phase timetable on the current infrastructure, and
- variant 3 is based on the new infrastructure model with increased speeds, a signalling system based on automatic block sections and implementation of clock-phase timetable.

### 5.1. Creating the RailSys model

The creation of the simulation model is a comprehensive job. It requires implementation of all the necessary data for the process of calculating and evaluation of data. During the process of model creation, it is very important to have valid data from all stakeholders in order to recreate real conditions of the track, vehicles and all other elements that will affect traffic. In general, it can be said that the process of creating a timetable starts with the creation of the infrastructure model. After the completion of infrastructure, the next step is to create rolling stock which is then used in the third step for timetable creation. The simplified process as described in this chapter is shown on Figure 16.



**Figure 16.** Creation of timetable in RailSys  
Source: [15]

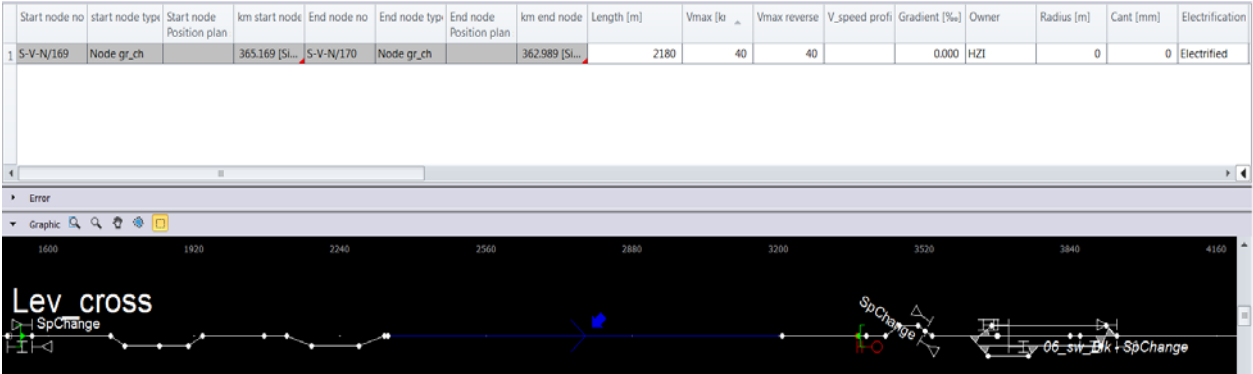
#### 5.1.1. Creation of infrastructure

The process of creating a RailSys infrastructure model starts in Infrastructure Manager. After collecting all the necessary data and the preparation of the idea, infrastructure is gradually

created. Infrastructure Manager has basic properties adjusted for users to start with model creation without any change in general properties. Project Data in RailSys allows for adjustments and definition of parameters specific for every simulation and environment. Master Data is a subgroup used to customize infrastructure and assign layers and names for all elements including level crossings, interlocking, signalling, countries, venues, data sources, classes of stations, closures and other.

When all attributes and layers are determined, the next step is to choose which type of view will be used for model creation. There is a choice between Line view, Microscopic view and Macroscopic view. It is recommended to use only one view during the creation of the model, although Line view is used for graphical representation of the timetable.

After setting up the initial properties for the creation of a line, it is important to create lines or global areas, which separate the timetable for different lines and capacity analysis. Global area represents the place (railway stations) where two or more lines connect. Besides from basic data such as line length, gradient, maximal speed it is possible to define electrification, line owner, axle loads, speed profile, radius, cant etc. As shown on Figure 17.



**Figure 17.** Line characteristics  
**Source:** [16]

Nodes are used to represent all changes and places on the line that have some effect on railway traffic. They are used for positioning of switches, level crossings, speed changes, signals, gradient changes. Each node must have a kilometre point and it is recommended to name every node.

Railway stations are created on existing infrastructure by implementing timing and stopping points or signals and must have boundaries from both sides of the station. A new station with an appropriate kilometre point and name is created in RailSys simply by selecting “Create new station”. All signals that are inside the station must be assigned to the station.



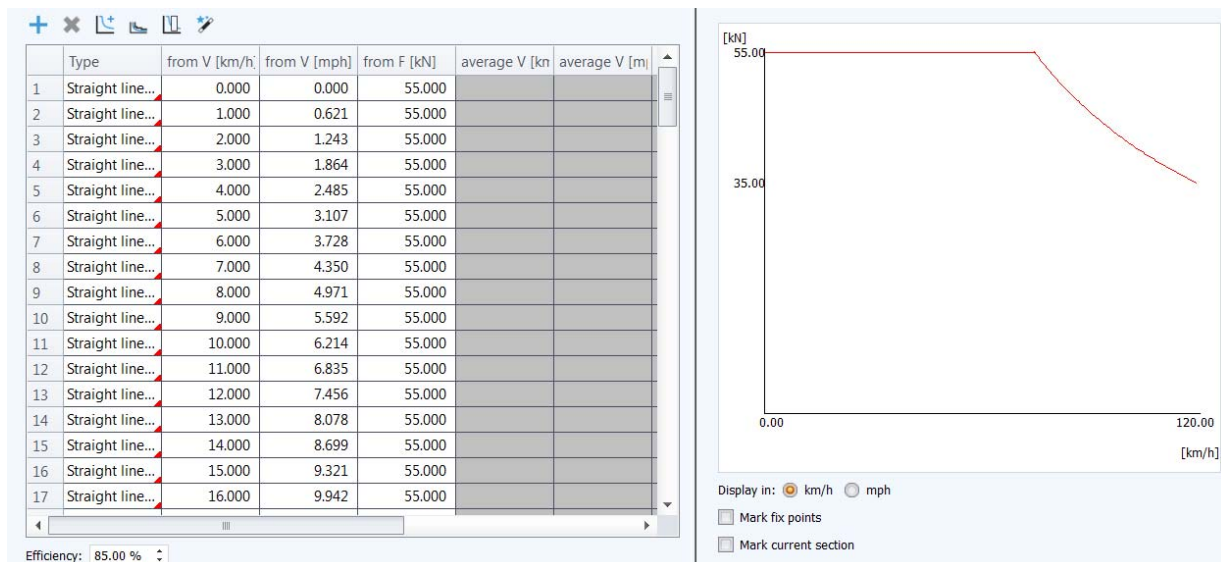
Signals in RailSys are divided into several categories and can be customized depending on different signalling systems that are used all over the world. Basic signals are M/P signals that are used mostly for the creation of models but there are several variations of these signals that can be used for different situations. Signals are divided into mechanical, electro-mechanical, electro-relay and electronic.

### **5.1.2. Creation of Rolling stock**

If all components of infrastructure are successfully created and there are no major errors, it is possible to start with the creation of rolling stock. Rolling Stock is created in the Timetable and Simulation Manager for the created infrastructure model. When creating railway vehicles there are several base elements that should be implemented:

- top speed (km/h),
- length (m),
- mass (t),
- adhesion mass (t),
- traction type (electric, diesel, hybrid, steam, battery),
- rotational mass,
- traction effort curve, and
- rolling resistance.

Except for base data, traction effort curve and rolling resistance curve are used for the creation of rolling stock. On Figure 18. it is possible to see the manually created traction effort curve. When creating a traction effort curve and rolling resistance curve it is recommended to insert more data points to have as realistic representation of train movement as possible.



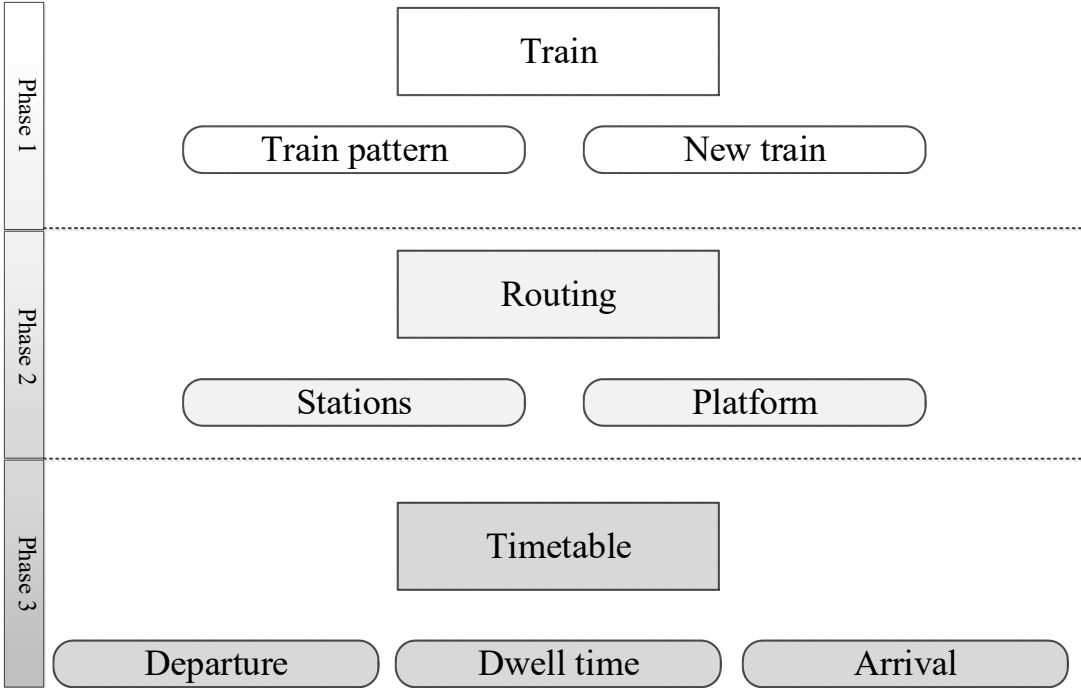
**Figure 18.** Default tractive effort curve for vehicle 6111  
**Source:** [16]

Vehicles can be classified in several categories based on distance (long distance or local trains), purpose (freight or passengers) and other (when train is not classified in above-mentioned categories). When created, rolling stock can be used to create train templates and sorted in different train patterns to easily manipulate train groups. It is recommended to create train templates that are later used for quick creation of necessary trains. All trains can be duplicated, deleted, created from a pattern, with many more possibilities which allow for easy creation of vehicles and trains.

### 5.1.3. Timetable creation

The timetable is a product of all combined elements that have been previously described and is the base for train operations. Depending on the collected information, the accuracy of the inserted data quality of the timetable can differ. A Timetable with high quality data is stable and flexible, which ensures reliable and precise train service. The process of timetable creation starts after the infrastructure model and rolling stock have been created. The creation of a timetable consists of several steps as shown in Figure 19. The first step is to create a train using previously created traction units, insert a trailer, and determine the signalling system and the type of the train (freight, passenger). Other options are to take already created train patterns or simply duplicate some of the already created trains. The next steps are to choose a departure and an arrival station (train route) and platforms for train run and/or stop (this data can be later altered if necessary). The last part of timetable creation is to implement departure, arrival and

dwell times. This part can be later modified in case there are some conflicts, or we want to try some other alternatives in the timetable. All changes done at later stages are immediately recalculated and shown in the timetable. Tools that allow for later changes in timetable give the user very good flexibility when testing different alternatives and finding solutions for potential conflicts that can occur. When selecting each train or several trains, it is possible to see all conflicts in the timetable by using the drop-down menu called State. Conflicts are marked with a bright colour in a graphical timetable and are easily recognizable.



**Figure 19.** Process of timetable creation  
**Source:** [16]

**5.2. A model for present state of infrastructure**

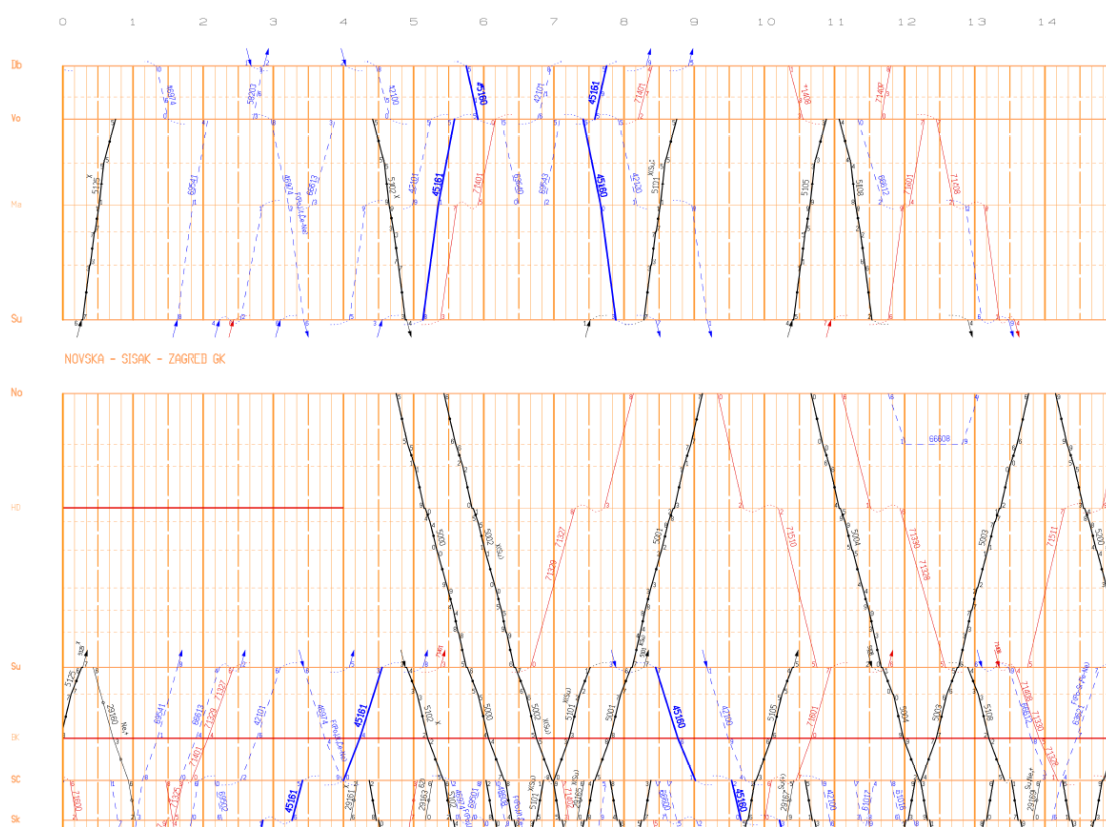
The model for the current timetable was developed using data from a Croatian railway infrastructure manager called Hz Infrastruktura. The data included cross-sections of the M 502 and R 102 tracks with all gradients, radiuses, lengths of each section, signals and official documents containing all elements for each station.

Rolling stock was created using data received from train operating companies both private and state-owned. This data includes timetables for each train that has departure, dwell and arrival times for each station on the train route and speed on each section of the track and in railway stations.

### 5.2.1 The current timetable

The creation of the current timetable is the first step towards developing a new clock-phase timetable. The current timetable was recreated to have a realistic infrastructure model which can be later tested in several ways to get the best alternative. The created timetable based on current infrastructure is called variant 1.

The timetable that is currently used on this part of the network consists of 28 freight trains, most of which run between Sisak and Volinja as well as 45 passenger trains with the main goal of transporting people from Sunja towards Sisak. Passenger transport is focused in the direction towards Zagreb, while Novska and Volinja are very poorly connected. There are only 4 passenger trains that drive from Sisak to Novska daily and 5 passenger trains in the other direction. Towards Volinja, there are 6 passenger trains per day and 5 trains in other direction. Most of the train traffic on this line is concentrated between Sisak and Sisak Caprag (14 passenger trains drive only from Sisak to Sisak Caprag). Figure 20. shows part of the timetable that is currently active on the lines mentioned.

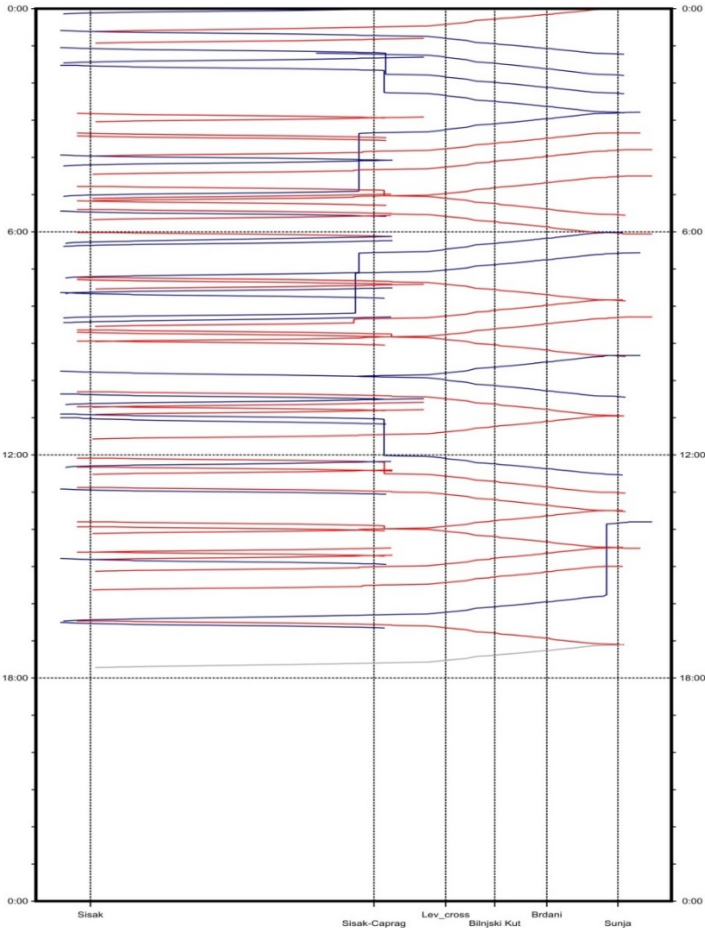


**Figure 20.** Partial timetable of the M 502 and R 102  
**Source:** [8]

The simulation model for variant 1 was created in RailSys using the timetable from Figure 20, the data from infrastructure manager and the data received from train operating companies. The timetable was simulated several times without any conflicts and lateness. After the creation of a stable simulation model, the timetable was compressed in the software (using the UIC method) to evaluate the current capacity utilization and track occupation.

The compression of the timetable was done on lines between Sisak – Sunja, Sunja – Novska and Sunja – Volinja for the duration of one day. These results will show a clear picture where the potential bottlenecks on this part of the network are, the capacity utilization of the track and where the first infrastructure modifications should be done in order to improve capacity.

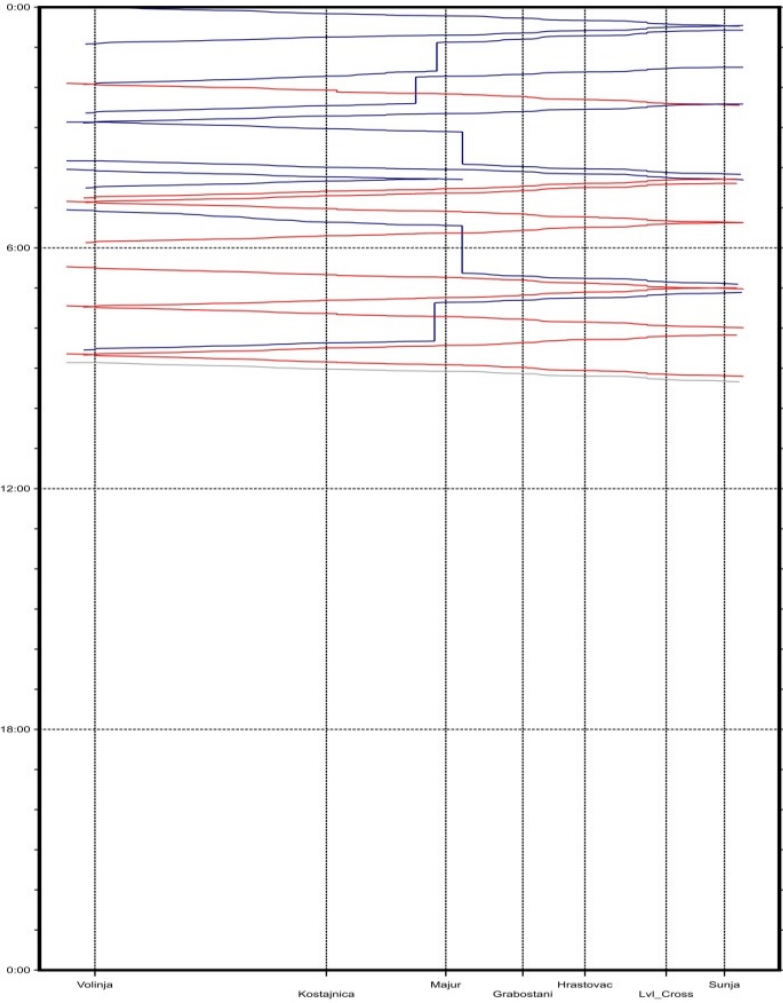
The Sisak – Sunja track is occupied for 61574/86400 seconds. The capacity utilization of the line is 71.3 %. There are 69 trains running on this line and 59 % of those are passenger trains. Figure 21. shows the capacity utilization between Sisak and Sunja.



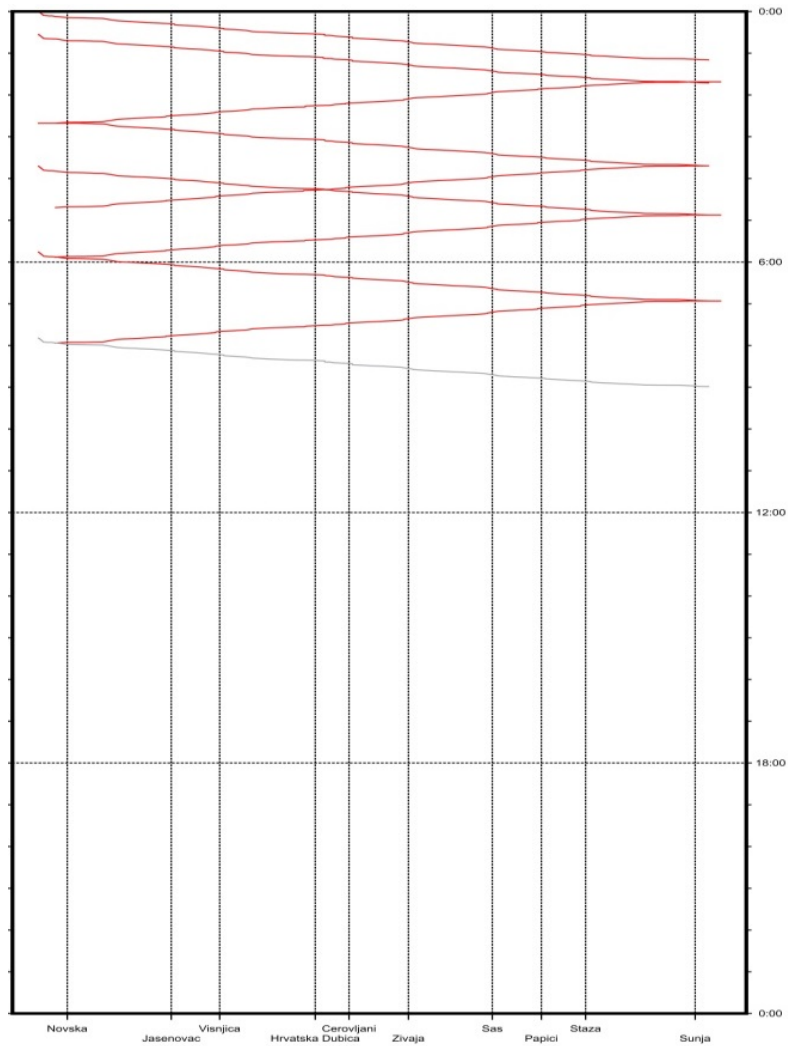
**Figure 21.** Capacity of the Sisak – Sunja line  
**Source:** [16]

Figure 22. shows the capacity utilization of the Volinja – Sunja line. The line between Volinja and Sunja (R 102) is occupied for 31894/86400 seconds. The utilization of the capacity on the line is 36.9 %, which is a little more than 1/3 of the capacity. Most of the trains that run on this line are freight trains and 48 % of the 21 trains are passenger trains. This line is predominantly used for freight transport towards Bosnia and Herzegovina.

The section of the line between Novska and Sunja has an occupation time of 28162 seconds as shown on Figure 23. There are only passenger trains running on this section of the line. The daily number of trains on the section of the line is 9 and that equals to a capacity utilization of 32.6 %. The reason for the lack of freight trains is the fact that Novska is connected to Zagreb by another railway line via Dugo Selo towards Novska.

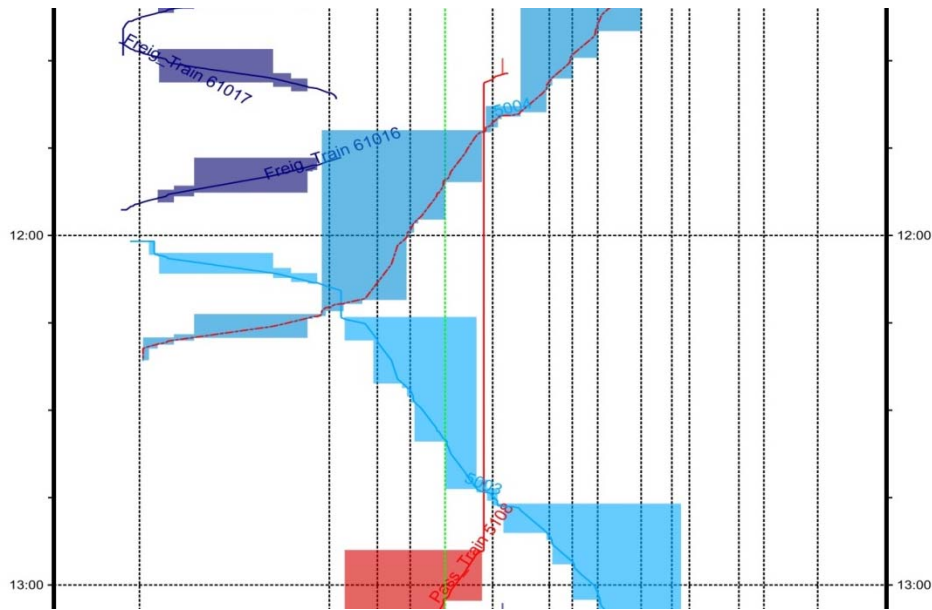


**Figure 22.** Capacity of the Volinja - Sunja line  
**Source:** [16]



**Figure 23.** Capacity of the Novska – Sunja line  
**Source:** [16]

After evaluating the lines and calculating the capacity it is clear that the section of the line between Sisak and Sunja has the highest capacity utilization and in case of implementation of new trains would be a bottleneck. The critical point on this part of the line would be the section of the line between Sunja and Sisak Caprag where we have two train stops that have only one track (no meeting points) and a non-secured level crossing where trains must stop before continuing their drive. This section of the track has no signalling and it uses non-signalled train operations. Due to the low maximum speed, the level crossing and stops it takes 31 minutes to cover this distance. This bottleneck is visible on Figure 24.



**Figure 24.** Bottleneck on the section Sisak Caprag – Sunja  
**Source:** [12]

### 5.2.2 The clock-phase timetable

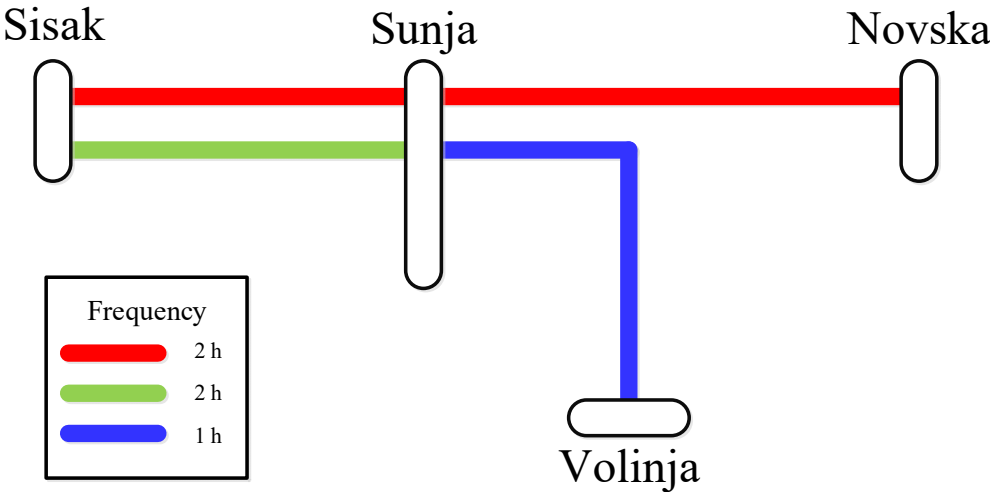
The current organization of the railway traffic on the lines has a generally very low capacity utilization and is not oriented towards development of passenger traffic. The organization of passenger transport based on a clock-phase timetable could be the solution to rejuvenating the railway traffic in the region.

I have built and simulated a clock-phase timetable in Timetable and Simulation Manager that runs on the existing infrastructure and with the existing vehicles used in the current timetable. The idea behind variant 2 and the implementation of this kind of traffic organization is to better use the capacity, reduce the number of vehicles but increase the number of trains running and to optimize transport. With the new clock-phase timetable with only a few circulating passenger trains it is possible to have a very good passenger service with acceptable travel times.

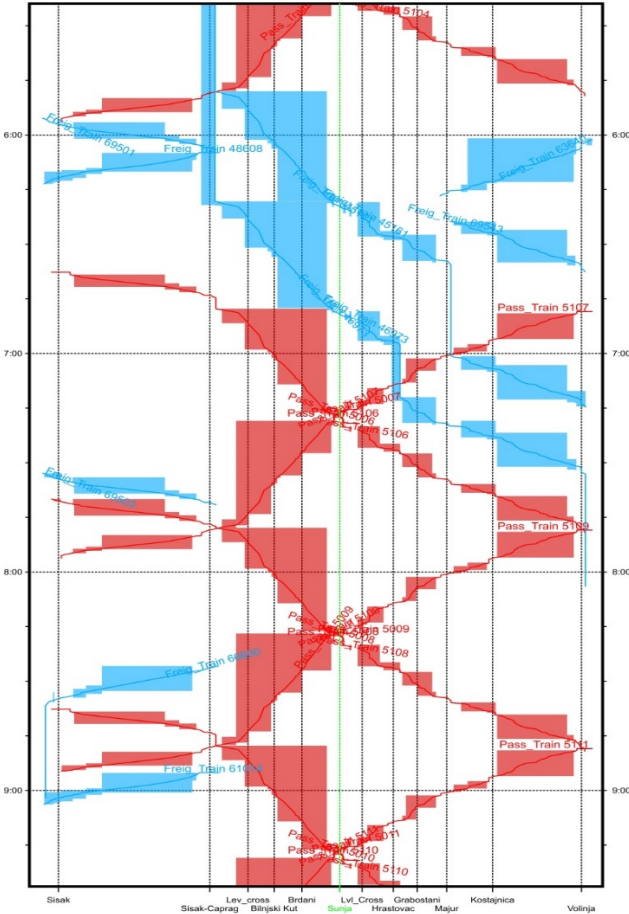
The new organization of passenger traffic is visible on Figure 25. The passenger trains are organized in a one-hour clock-phase timetable between Sisak – Sunja – Volinja and a two-hour clock-phase between Sunja and Novska. For the realization of this timetable, it is necessary to have five trains that will circle all the time. The train that travels from Sisak to Novska will arrive at Novska and at a predetermined time travel back to Sisak. This kind of organization allows for a smaller number of vehicles that run a higher number of train runs. Trains depart from stations at predetermined times from Sisak, Novska and Volinja. Due to the constraints in the infrastructure and just a few meeting points, departure times from each station must be



perfectly adjusted. Part of the timetable is shown on Figure 26. where the clock-phase of the passenger trains is visible.



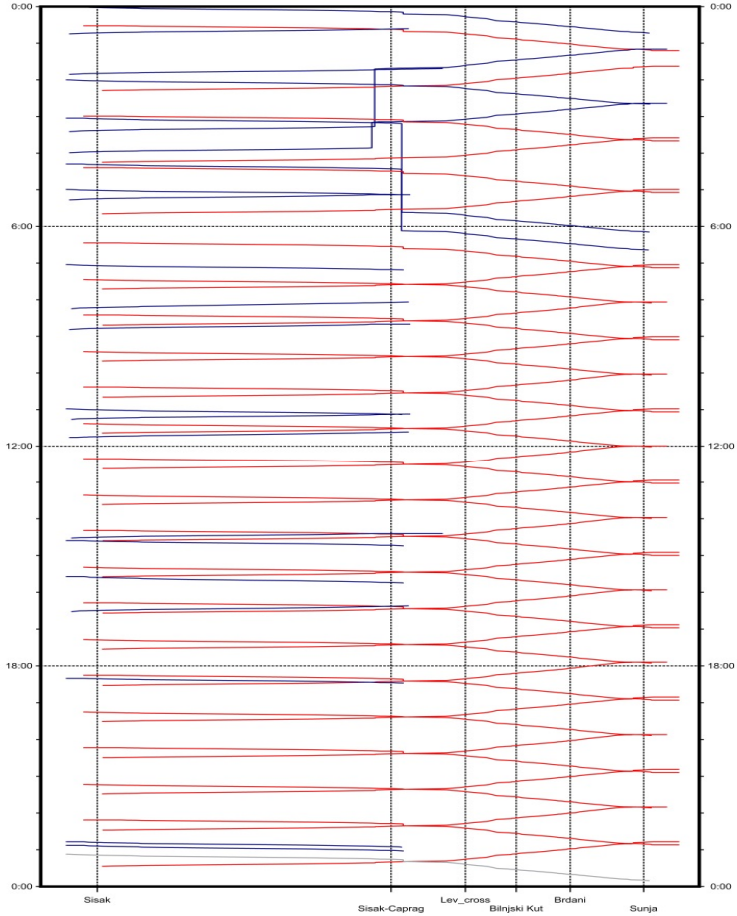
**Figure 25.** New traffic organisation of passenger transport  
**Source:** [16]



**Figure 26.** Clock-phase timetable  
**Source:** [16]

The number of trains differs during the day. From 00:00 till around 06:30 there is a two-hour clock-phase on the all lines. This “gap” in the timetable is used for the transport of the freight trains, which cannot run during the day because of the high intensity of the passenger trains on the line. Before first peak hour in the morning, a one-hour clock-phase timetable is established between Sisak – Sunja – Volinja and it lasts until midnight.

On the whole network there are 80 passenger trains and 25 freight trains. From all freight trains in the current timetable, 3 trains could not fit in the timetable because of the lack of capacity. On the section between Sisak and Sunja, capacity utilization with the clock-phase timetable is 96.3 %. This means that 83227 of 86400 seconds during the day line are occupied. There are 63 trains on the line of which 40 are passenger trains and that corresponds to 63 % of trains. On the figure 27. It is clearly visible that the clock-phase timetable on the existing infrastructure has a very high capacity utilization and that there is a small space for implementation of new trains in timetable.



**Figure 27.** Capacity of the Sisak – Sunja section  
**Source:** [16]

The section of the line from Sunja to Novska is used far more than in the currently active timetable. People who travel from Novska to Sisak now have the option of transferring to a train going towards Volinja in under two minutes at Sunja Station. After the compression of the timetable, the capacity utilization on this section of the line is 54.7 %. During the course of the whole day the track is occupied for 47292 seconds. The Total number of the trains between Sunja and Novska is 24 and all the trains are passenger trains.

In the new traffic organization, line R 102 from Volinja to Sunja has become a very important line for transport of passengers. People traveling from Volinja towards Sunja now have the option to travel towards both Novska and Sisak depending on the preference and have the opportunity to work, study and attend leisure activities in bigger cities. A reliable one-hour clock-phase timetable enables mobility for those who will use these trains for day-to-day commuting. Occupation time of the line is 36082 of 86400 seconds, which corresponds to a capacity utilization of 41.8 %. The limiting factor for further development of train services on the lines is the section of the line between Sisak and Sunja which is directly affecting the number of trains that can travel towards Volinja. There is a one-hour clock-phase on the line starting from around 06:30 and ending around midnight where a two-hour clock-phase is implemented until the morning rush hour. The number of trains on the line is 48, 84% of which are passenger trains (40 passenger trains). The turnover of trains requires two trains per day that drive constantly in circle.

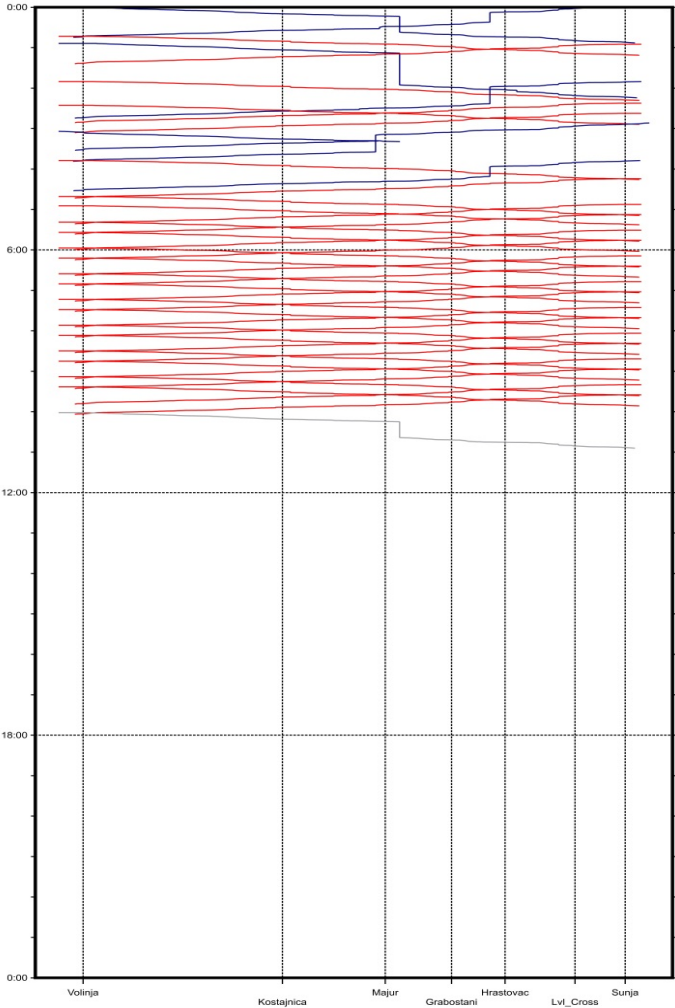
**Table 1.** Times for transfer of passengers in Sunja (seconds)

<b>From / To</b>	<b>Sisak</b>	<b>Novska</b>	<b>Volinja</b>
<b>Sisak</b>	-	-	110
<b>Novska</b>	-	-	90
<b>Volinja</b>	93	83	-

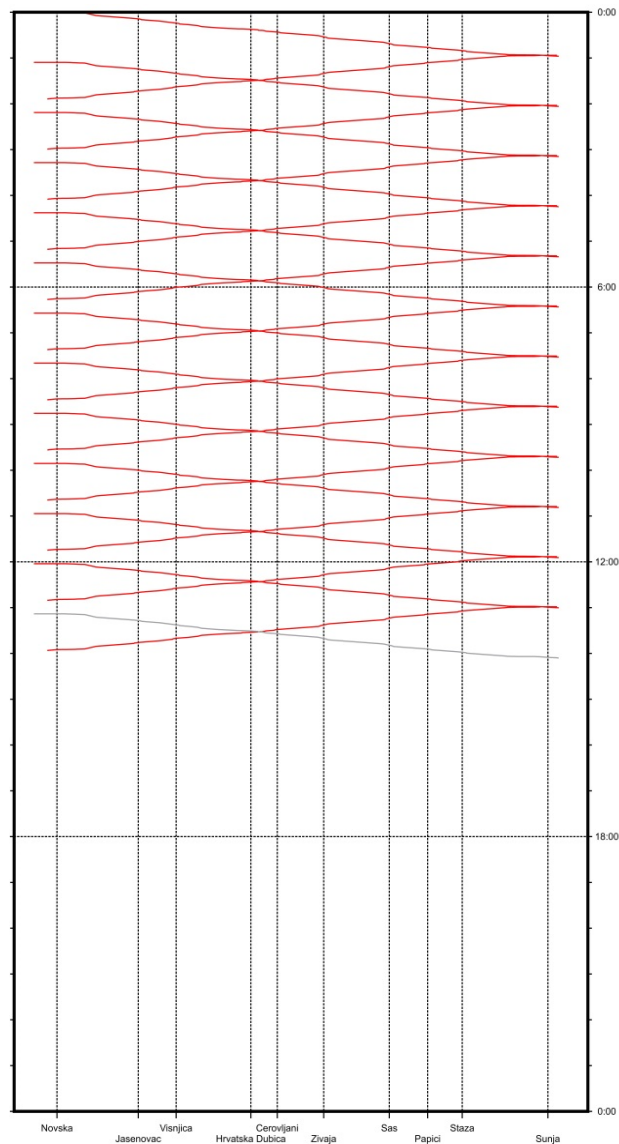
Source: [16]

Due to the constrains in infrastructure and very high capacity utilization of the Sisak – Sunja section it is necessary to have times for transfer of passengers higher than 60 seconds. This kind of organization gives passengers possibility to make transfer in Sunja and travel in every possible direction with transfer time under 120 seconds.

On Figure 28. We can see compressed timetables for Novska – Sunja and Volinja – Sunja lines. Considering the available capacity on the lines, the section of the line between Sisak and Sunja with very high capacity has an explicit effect on these two sections and is limiting traffic on both sections. The best solution for capacity would be to do implement infrastructure changes on the section between Sisak and Sunja in order to balance traffic flow on all of the lines and better utilize corridors towards Novska and Volinja. Although there are 48 train runs on the Volinja – Sunja line compared to 24 trains on the Novska – Sunja line capacity occupation on the Volinja – Sunja line is significantly lower than capacity occupation of the Novska – Sunja line (41.8 % compared to 54.7 %). This difference is due to the limitation between Sunja and Hrvatska Dubica (direction Novska) where a train is blocking the whole path because there are no meeting points for trains. The travel times of the freight and passenger trains are the same as travel times on the currently active timetable because no changes on infrastructure or signalling have been made.



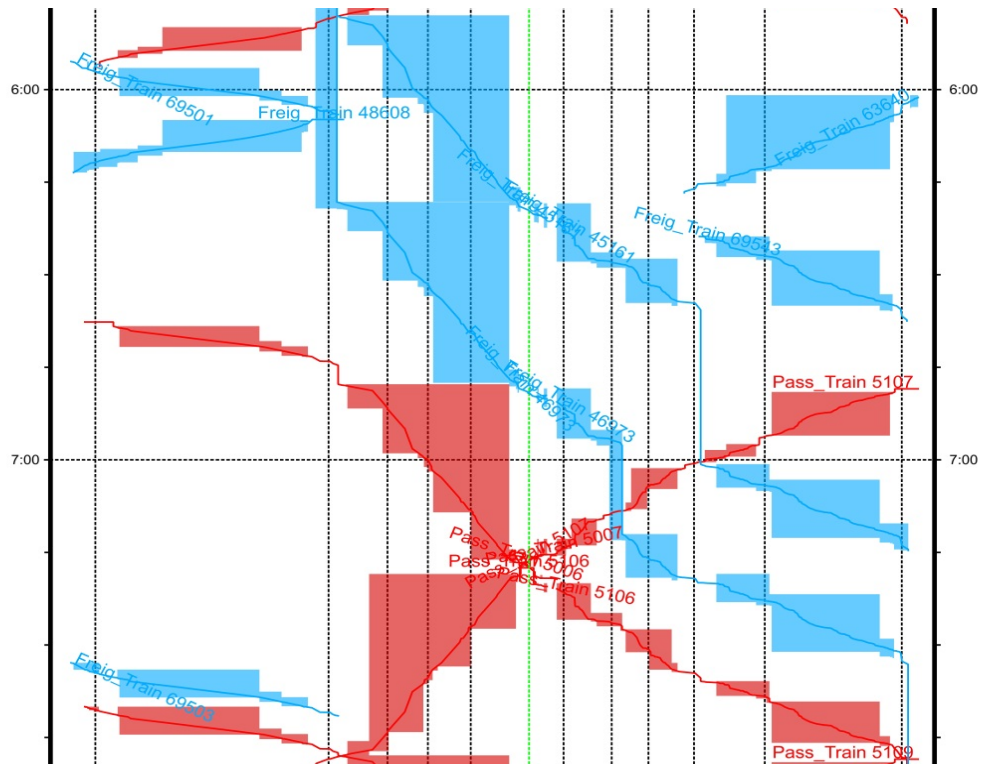
**Figure 28.** Capacity of the Volinja – Sunja line  
**Source:** [16]



**Figure 29.** Capacity of the Novska – Sunja line  
**Source:** [16]

Figure 30. shows the occupation of block sections and limitations of the non-signalled train operations on the clock-phase timetable between Sisak and Sunja. It is visible that a one-hour clock-phase timetable starting around 06:30 is necessary because of the freight trains that use the early morning “gap” to cross this path one after the other.

As mentioned before, the limiting factor for this line is section of the line from Sisak Caprag to Sunja where there are not any meeting points for trains. This section of the line is fully occupied and there is no free capacity on this section for the implementation of trains.



**Figure 30.** Timetable of the Sisak – Sunja – Volinja line  
**Source:** [16]

Theoretically, approach for this timetable allows all trains to run without any problems but in real world operations, there is a high probability of unpredicted events that could affect one or several trains and cause delays.

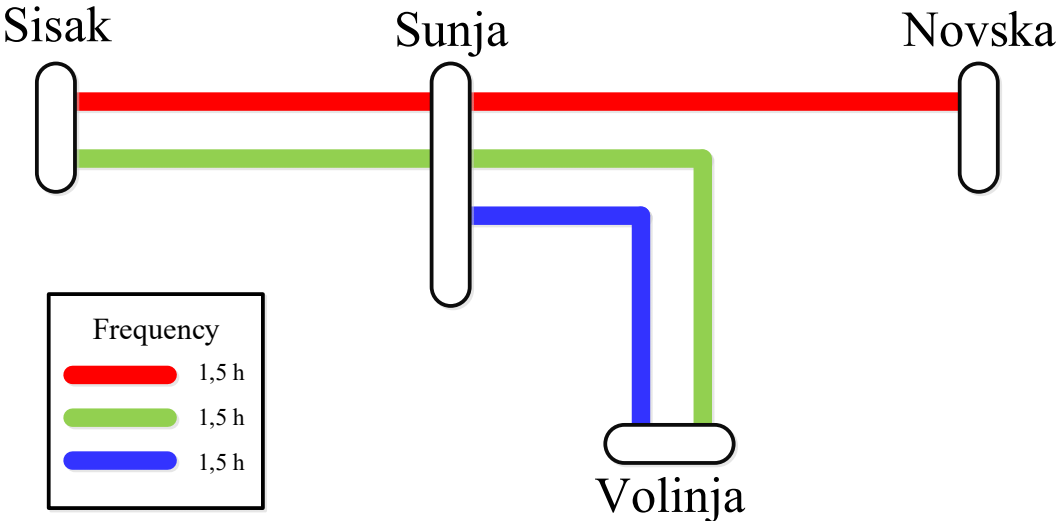
### 5.3. A model of the future state of the infrastructure

The development of the model that will improve service on the line and set up the foundation for the creation of quality passenger traffic with high speeds and reduced travelling times for interregional trains requires infrastructural and organizational improvements. These improvements will modernize lines and make significant steps towards sustainable traffic and high passenger flows stimulating the switch from car to rail. The idea behind this is to reduce travel times and have better service that will prompt people to choose the rail as their first choice of transport.

The new model of infrastructure features the same stations and tracks as before with changes affecting signalling and speed of tracks. The speed of the tracks is increased to the maximum speed of 120 km/h, and on the sections where the radius of the curve is smaller than 300 meters

the speed is set at 100 km/h. The railway stations have a speed of 40 km/h except for several stops that already had a maximum allowed speed of 60 km/h. Quality passenger service requires an upgrade of non-signalled train operations to automatic block signalling. This change in signalling systems would reduce occupation of the block sections and significantly improve the capacity of the lines. All railway stations are protected with signals. Distant signals that make automatic block sections are set on every 800 to 1300 meters depending on the infrastructure situation and are oriented in both directions of the lines. Due to the modernization of the signalling system, it is no longer necessary to stop at level crossings. Level crossings are upgraded and equipped with all the necessary security equipment. New equipment on level crossings means that crossings are now automatically controlled with block occupation. This set of measures is tested and simulated with the 45-minute clock-phase timetable on section between Sisak – Volinja and 90 minutes clock-phase timetable between Novska and Sunja. There is a 25 % increase of passenger train service between all stations of the network. Additional upgrades include a buffer time of 30 seconds and standard allowance time of 3 %. Increase in speed, new signalling system, buffer times, standard allowance times are combined measures for high quality service, stable and flexible timetable.

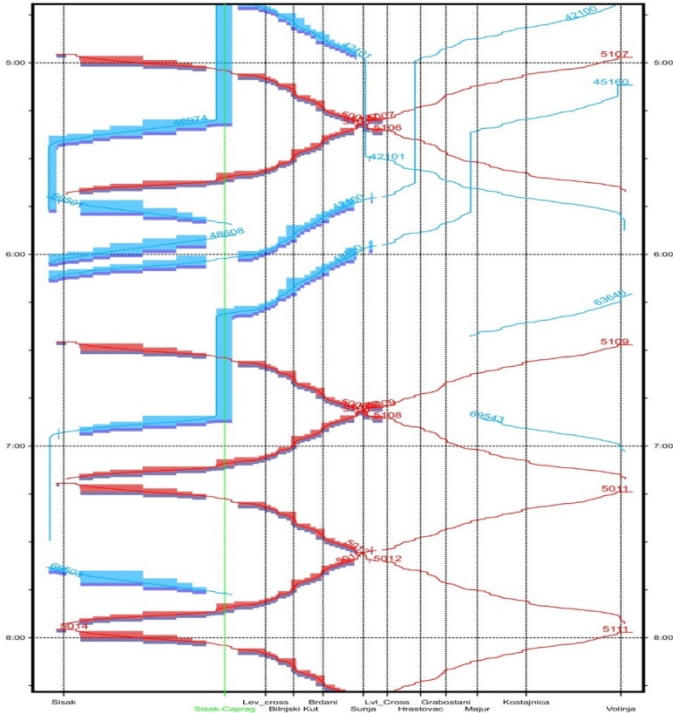
Figure 31. shows the organization of the new proposed timetable and clock-phase timetable on the selected lines. People travelling from Sisak can now every 45 minutes travel either directly or with one transfer to and from Volinja and every 90 minutes to and from Novska. Dwell times in Sunja are set up so that all people transferring to a different train in Sunja and travelling in any direction have around 60 seconds to make the transfer if necessary.



**Figure 31.** Clock-phase timetable on improved infrastructure  
**Source:** [16]

With this organization of traffic, Sunja has become a hub for passenger traffic. This organization means that people from the whole region have at their disposal passenger services that will secure commuting and leisure travels without any danger of waiting a long time to travel back to their homes. Through increase of the speeds on the lines, trains are now competitive to cars when talking about travelling times. A comparison of travel times can be found in the next chapter.

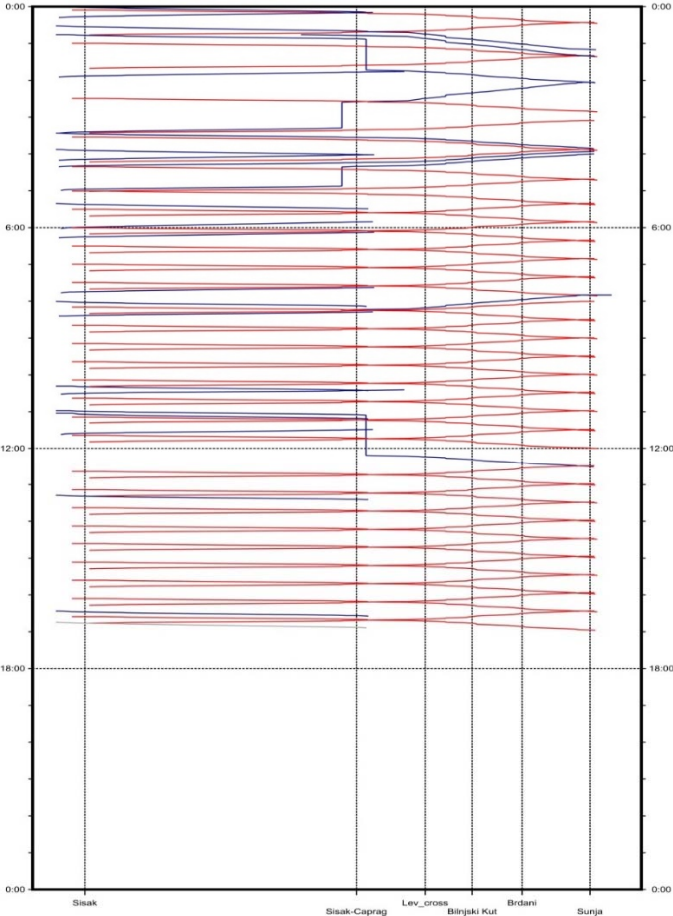
The organization of the traffic on aforementioned lines is similar to variant 2 with a clock-phase timetable, but with a reduced time for the clock-phase to 45 minutes. Figure 32 shows the effect of the new signalling system on the occupation of the sections on the line. The separation of the lines on the blocks has reduced unnecessary waiting times for trains who had to wait before leaving a station until a whole section is cleared in non-signalled operations. The best example of this is the section of the line between Sisak Caprag and Sunja where it is now possible to send trains one after the other if necessary and the whole section is no longer occupied when one train enters sections as before. The problem of the meeting point on this section remains, but the fact that speeds are significantly increased means that there are more trains that can run on this section through the course of the day. With the morning peak hour trains start to run on 45-minute clock-phase around 06:30. Time before the morning peak hour is reserved for the transport of the freight trains to their destination.



**Figure 32.** Timetable of the Sisak – Volinja line  
**Source:** [16]



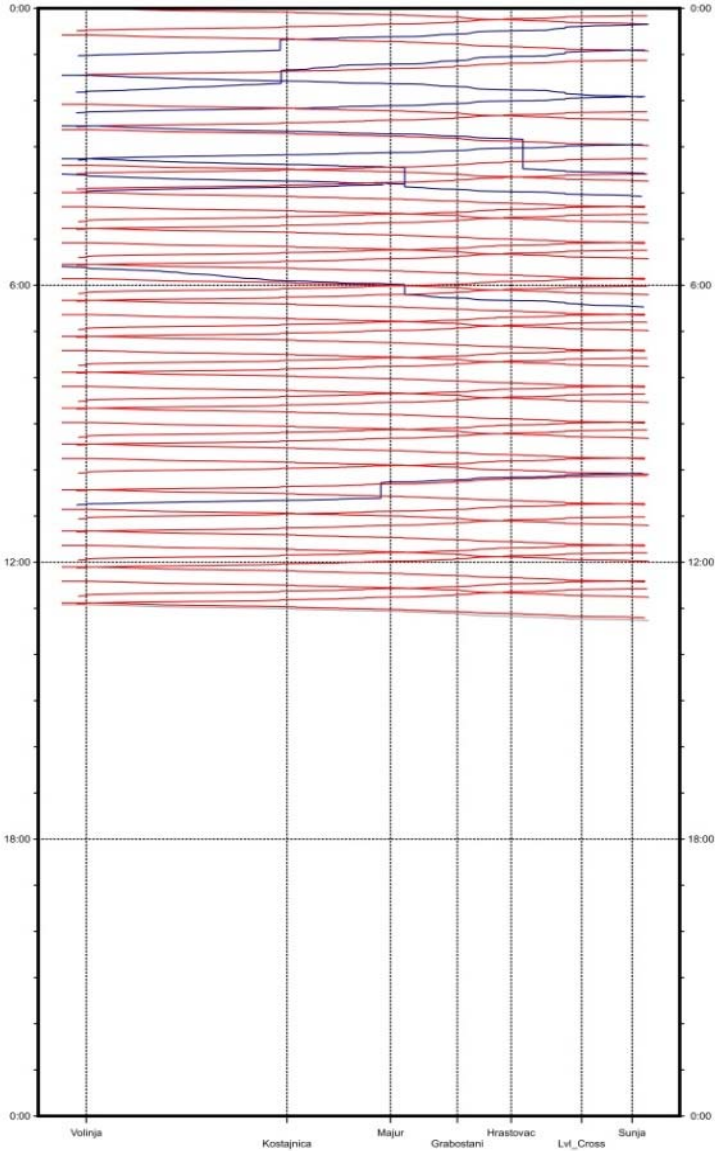
The section of the line between Sisak and Sunja is occupied for 60274 seconds during the course of the day with the capacity utilization of 69.8 %. Daily number of trains on the section is 81, 55 of which are passenger trains. This data shows that the Sisak – Sunja section is predominantly reserved for passenger transport with 68 % of passenger trains. Passenger trains that are running on the track have a low turnaround time and it is possible to have this kind of passenger service with only 4 trains circulating all the time. The capacity of the line is limited by the already mentioned part of the line between Sisak Caprag and Sunja since there aren't any meeting points on this section. The limitation of the line is shown on Figure 33 by looking at the compressed timetable and the occupation of freight trains in the timetable. Except from the passenger trains that run in clock-phase all freight trains from the currently active timetable are implemented and are running in the simulation. A decrease of the capacity utilization by 28 % and an increase in train rides by 29 % in comparison with the previously tested clock-phase timetable (variant 2) means that the capacity of the section is better utilised, and that efficiency has been increased.



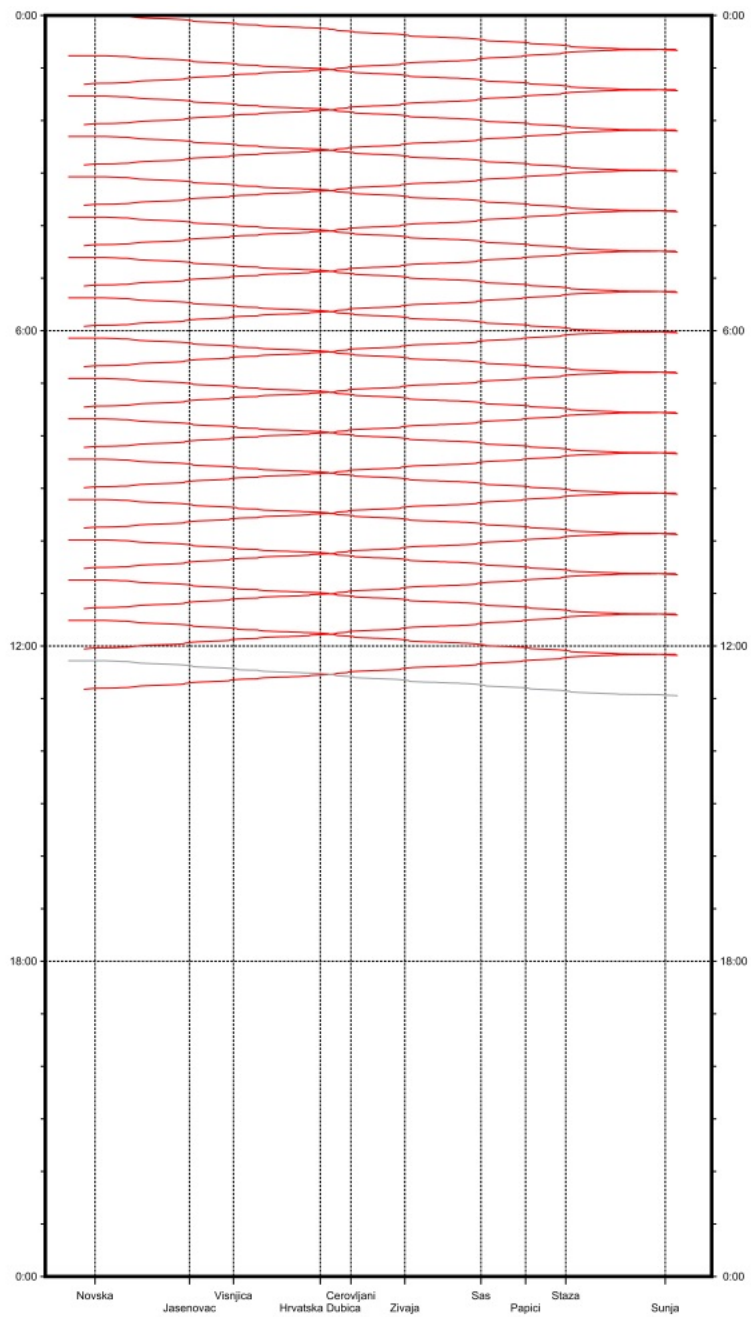
**Figure 33.** Capacity compression on the Sisak – Sunja section  
**Source:** [16]

The Sunja – Volinja line (R 102) has been occupied for 46522/86400 seconds what means that the capacity utilization is 53.8 %. Passenger transport has taken major role on the line where 55 of 66 trains are passenger trains. That puts the number of passenger trains to 83 % of all traffic on the line. Considering the number of trains and the capacity utilization it could be said that the line still has great potential for further development.

With the reduced clock-phase to 90 minutes section of the line between Novska and Sunja has increased number of trains by almost 33.3 % the line has been occupied for 44212 seconds of one day. Capacity utilization of the line is 51.2 % with 32 train runs per day. There are only passenger trains running on the line. the Compressed timetables of sections from Volinja and Novska towards Sunja are shown on Figure 34 and Figure 35.



**Figure 34.** Capacity of the Volinja – Sunja line  
**Source:** [16]



**Figure 35.** Capacity of the Novska – Sunja line  
**Source:** [16]

## **6. A Comparative analysis of simulation models**

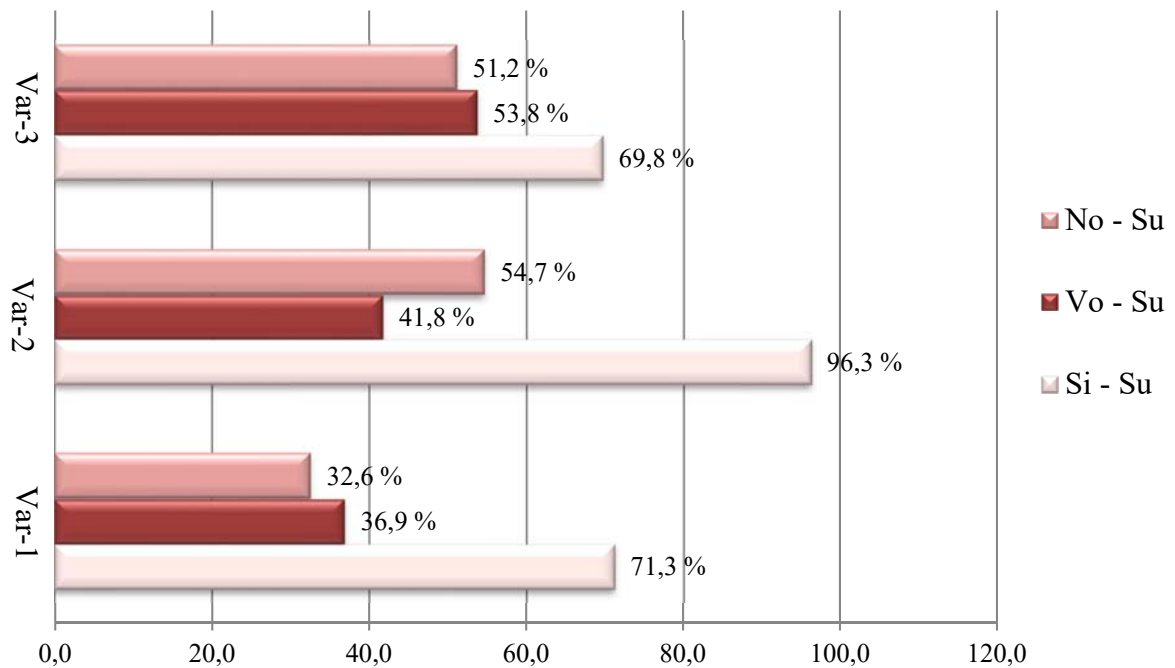
Through this chapter, simulation variants 1, 2 and 3 will be compared and analysed. Using the RailSys software there are three different sets of data that are compared through capacity occupation, occupation of selected tracks, stations and travelling time as a product of the newly established terms in the third simulation (speed increase). Variants are determined by different timetables starting with variant 1 (var-1) which is recreating the current timetable on the line. Variant 2 (var-2) is presenting the simulation with the clock-phase timetable on the old infrastructure and finally variant 3 (var-3) is data extracted from the third simulation with an increase in speed and a new signalling system. The chapter will compare these variants and will provide best solution for this part of the network.

### **6.1. Capacity occupation**

The selected lines are compared using data extracted from RailSys. The data was created through compression of the timetables on the sections between Sisak – Sunja, Volinja – Sunja and Novska – Sunja. Capacity occupation of the lines has been calculated using the UIC method. A Comparison is made for all created variants of the timetable.

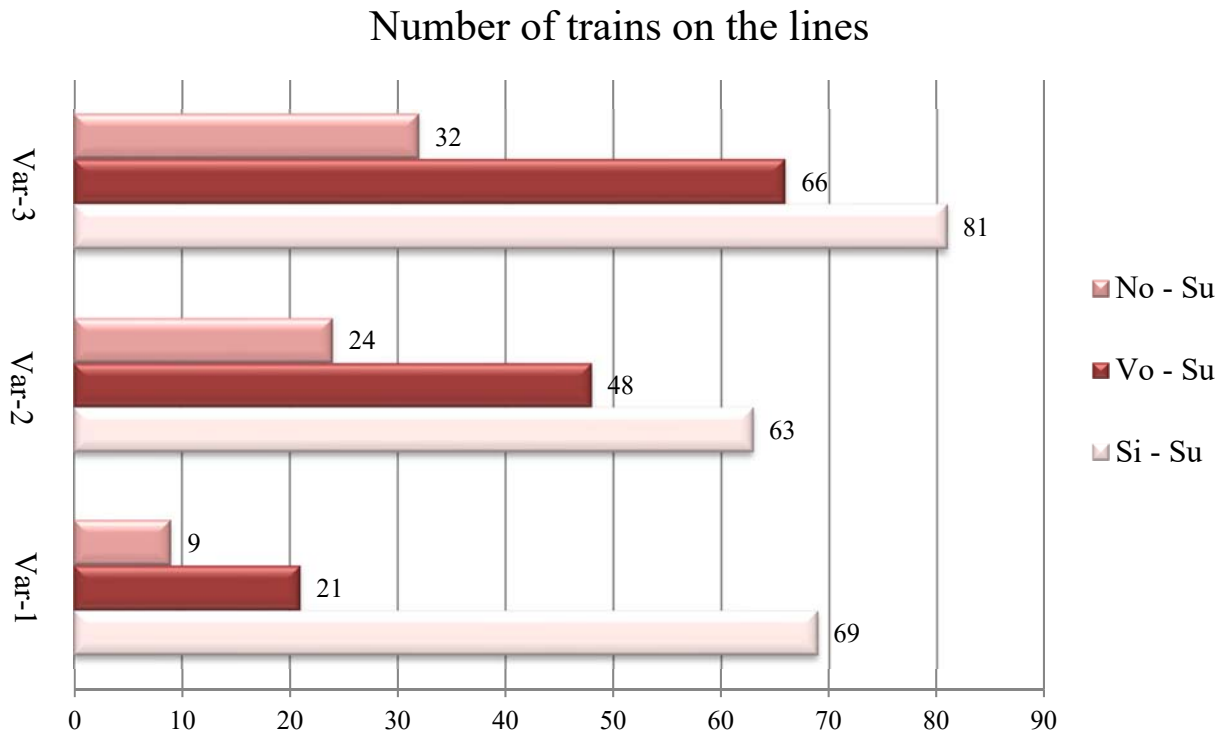
Diagram 1 shows a comparative analysis of the capacity occupation on the stated lines. Based on the results, the section of the line between Sisak and Sunja is a critical section and the limiting factor for this part of the railway network. The results for the capacity occupation of the variant 3 are quite interesting. The capacity occupation of the lines has decreased on all lines except on the Volinja – Sunja line. This means that the increase of speed and the implementation of different signalling system has opened a new space for trains to run. It is also possible to see that the capacity occupation is better balanced between lines when comparing this result to the capacity occupation on the previous variants. In variant 3 the Sisak – Sunja section is still the bottleneck of this network, but the influence of this bottleneck on the rest of the network has decreased with the increase in speed. There is also a significant increase in capacity utilization on variant 2. The implementation of clock-phase timetable and increased number of trains have affected the capacity of the track to the point where line between Sisak and Sunja is fully occupied.

## Comparison of capacity occupation



**Diagram 1.** Comparison of capacity occupation  
Source: [16]

From Diagram 2 we can see an increasing number of trains runs per variant. The exception from the increasing number of trains per variant is the situation where variant 1 has more train runs on the Sisak – Sunja section than variant 2. This is due to the high number of short train trips between Sisak Caprag and Sisak most of which are run empty because of the necessity to return empty passenger trains to Sisak. The highest number of train runs is in variant. Significant improvements in speed and signalling has affected the capacity and reduced capacity occupation in regard to variants 1 and 2. An example of this is the number of trains on Volinja – Sunja line. In variant 1 the number of trains is 21 while on the same section in variant 3 the number of trains is 66. This is an increase of 3,1 times while capacity occupation has increased 1,5 times.



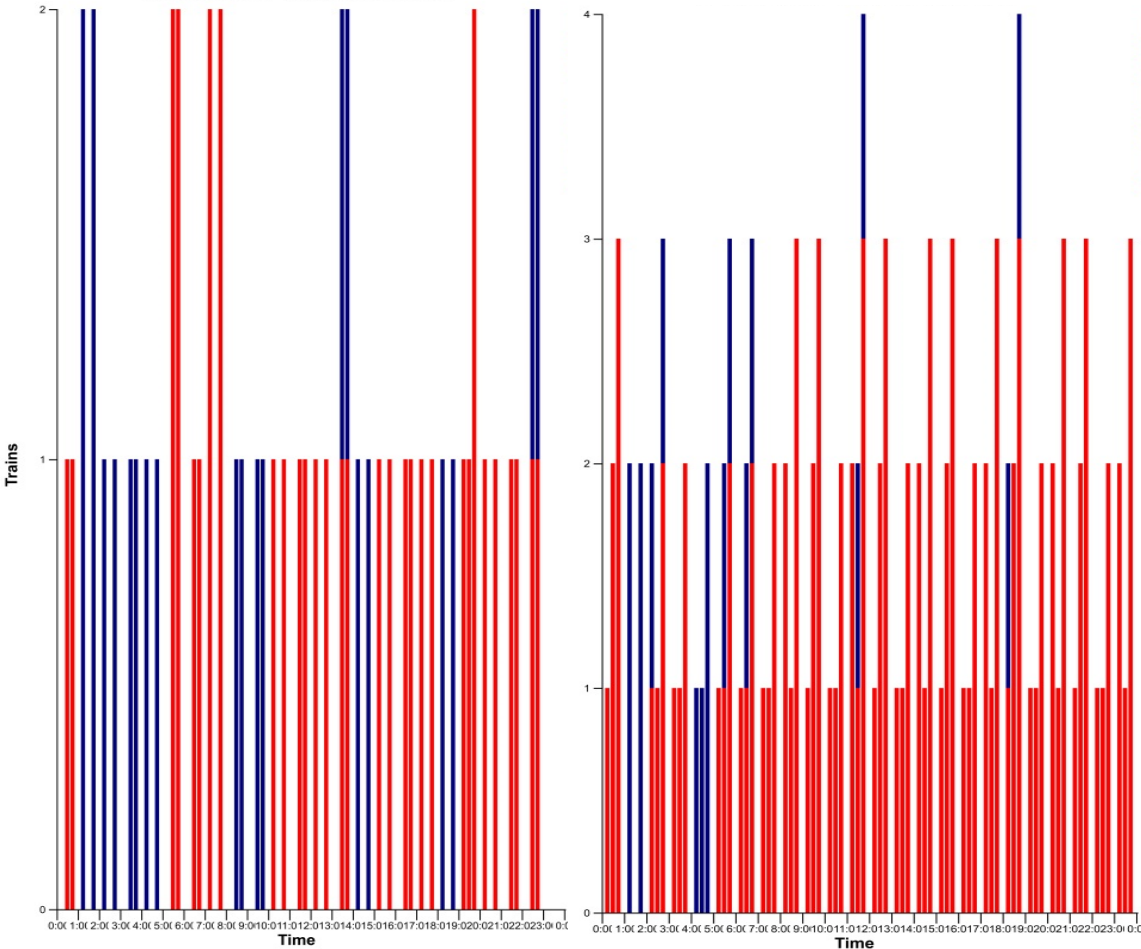
**Diagram 2.** Number of trains on the lines  
Source: [16]

## 6.2. Track occupation

One of the most important indicators of capacity and organization is track occupation. Track occupation in RailSys is measured between two stations of choice. For calculating track occupation, I have selected three sections that will be used for comparing the capacity. The separation of sections is according to Sisak – Sunja, Novska – Sunja and Volinja – Sunja lines on the parts where there are potential bottlenecks. The selected sections reflect points where meeting points of the lines are the furthest away, and the limitations of lines could be based on the occupation of these sections.

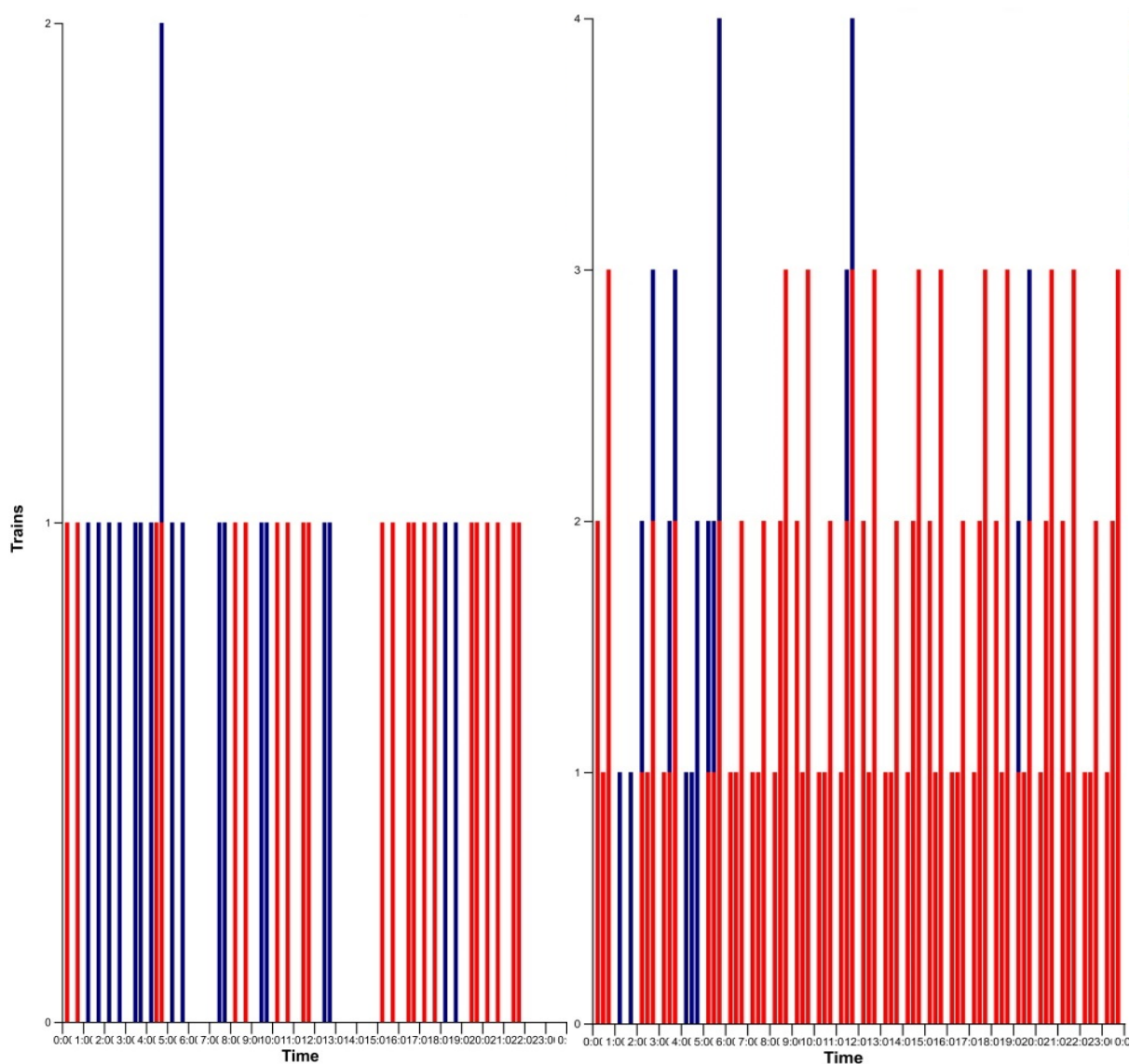
A Comparison of the track occupation between Blinjski Kut and Brđani (part of the Sisak – Sunja line) is shown on Figure 36. A comparison of track occupation is made for variant 1 and variant 3 of the timetables. The highest track occupation is in variant 3 where during peak hours 4 trains per hours are travelling through this section. On the current timetable the highest number of trains per hour is 2. In variant 2 with the clock-phase timetable train organization on the existing infrastructure has been optimized and there are 3 trains per hour at peak traffic. On

the existing infrastructure 3 trains per hour is the highest possible number on this section of the track due to the limitations in speed and signalling.



**Figure 36.** Comparison of track occupation (Blinjski Kut - Brđani)  
**Source:** [16]

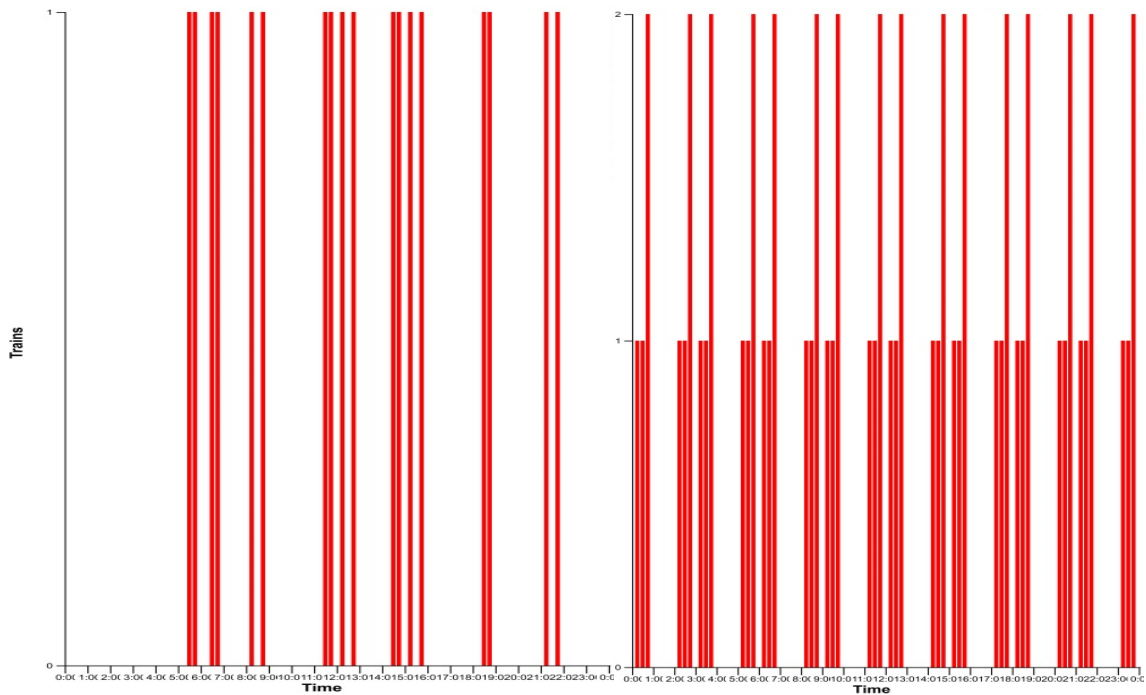
For the comparison of the Volinja – Sunja line, section of the line between Hrastovec and Graboštani has been used as shown on Figure 37. This is a section with no meeting point in neighbouring stations and has been detected as a potential bottleneck of this line. As expected, this track has the highest number of trains in the variant 3, and the lowest number of trains per hour in variant 1. In general, this line is limited by connecting line M 502 and currently has no problem accommodating all trains that departure from Sunja towards Volinja. Capacity and track occupation are not high and there are enough meeting points for both passenger and freight trains.



**Figure 37.** Comparison of track occupation (Hrastovec - Graboštani)  
**Source:** [16]

A comparative analysis of the Novska – Sunja line where I have selected section of the line between Šaš and Papići for evaluation is shown on Figure 38. In timetable variant 1 this section of the line is occupied by only one train per hour. The implementation of the organizational changes in passenger traffic has increased that number to 2 trains per hour during peak traffic (variant 2). The increase in speed and new signalling system in variant 3 result with the same highest number of trains per hour as in variant 2.





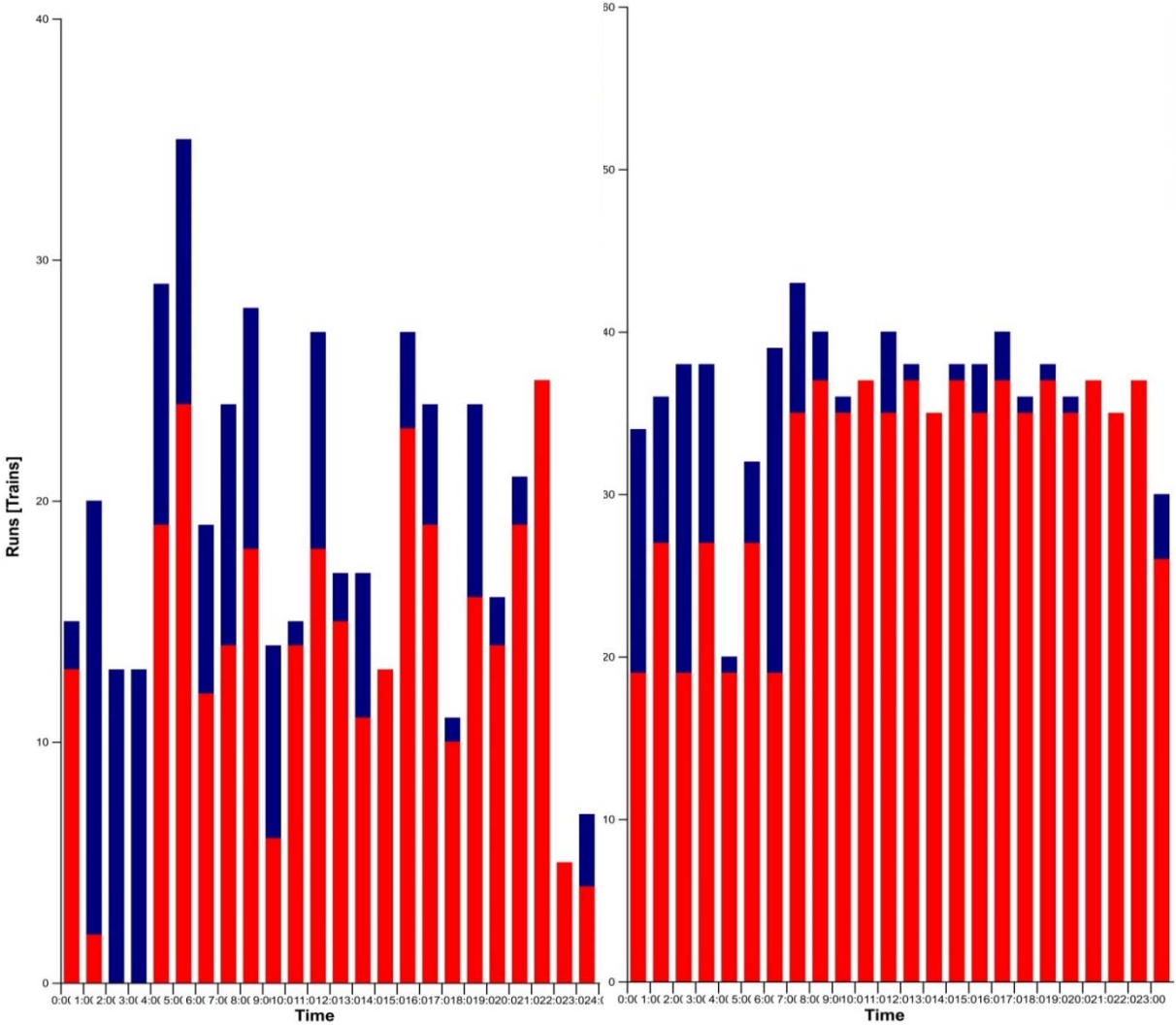
**Figure 38.** Comparison of track occupation (Papići - Šaš)  
**Source:** [16]

### 6.3. Occupation of railway stations

Changes through different variants from the current timetable to a clock-phase timetable, the increase of speed and the change in signalling systems have affected both tracks and stations. Track capacity has increased with organizational and infrastructural changes while railway stations must process a higher number of trains with the same capacities. We will evaluate changes in occupation of stations and make a comparative analysis of the railway station Sunja used as a meeting point for trains and transfer of passengers which, in the end, is processing the highest number of trains. The main idea is to see whether the station will be able to handle an increasing number of trains and changes in traffic organization or it will prove that Sunja station is the bottleneck for these lines. Through the next several figures, we can see the effect of changes through all variants.

The occupation of railway stations shows the number of trains per hour in all stations on the lines as visible on Figure 39. Changes in organization have made an impact on the occupation of stations. In the variant 1, there are approximately 15 trains in the stations at any given moment. In variant 2 the number of trains increases to around 25 trains in all stations, which is an increase of 67%. It means that the stations are processing more trains with the same

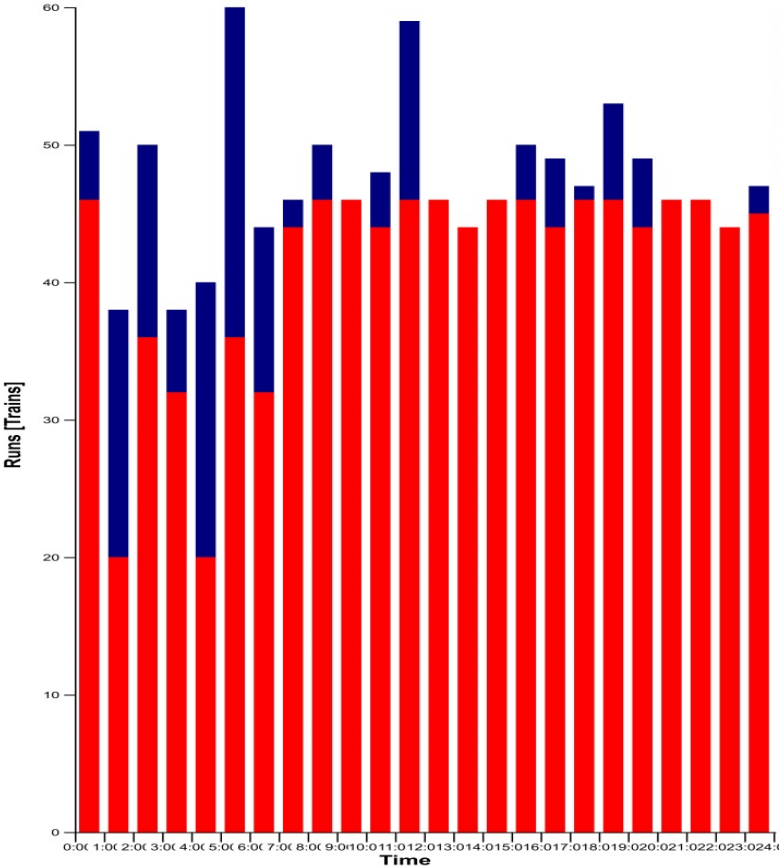
infrastructure capacity. This increase shows that the stations are well equipped for an increase in traffic but raises the question of the necessity of improving the bottleneck between Sisak and Sunja where capacity utilization is around 96 %. The traffic on the variant 2 is better distributed and the reorganization of the traffic has made an impact on the overall picture of the daily occupation of stations.



**Figure 39.** Comparison of occupation of all stations for (var-1 and var-2)  
**Source:** [16]

In variant 1 we can see unequal distribution of trains through one day. The highest occupation is in morning around 05:00 with around 32 trains while in the evening after 22:00 occupation of railway stations is minimal. In variant 2 this difference has been corrected with similar occupation of the stations during day caused by better traffic organization.

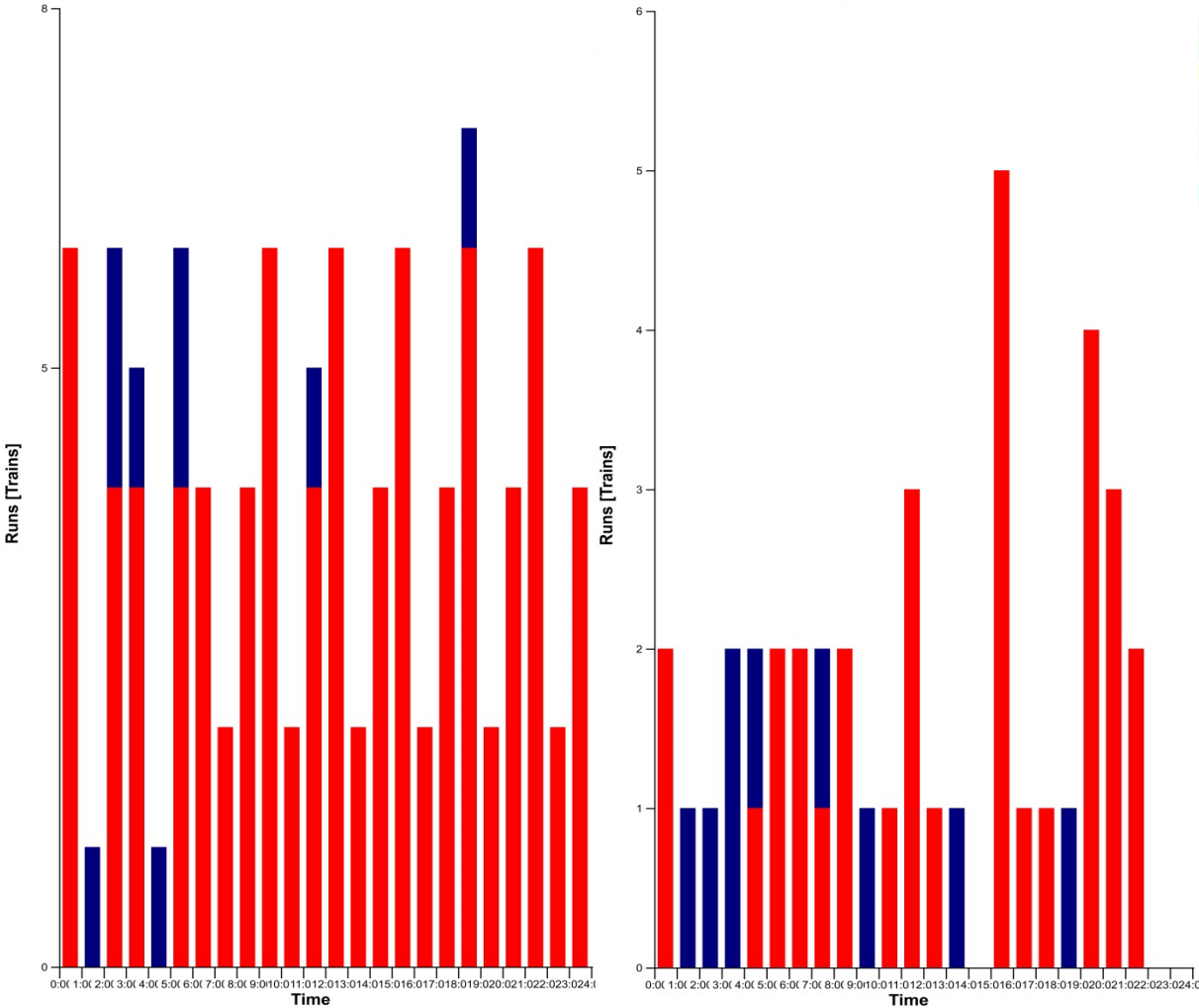
Infrastructure changes in variant 3 mostly affect the tracks while only the signalling system has been changed in the stations themselves (and a smaller increase in speed for some stations). These upgrades were aiming to make corrections on the capacity of the track because the track is seen as the limiting element of this network. After the significant improvements (especially in speed), the new capacity has been “created” and the network has the potential to accommodate a further growth of traffic. Occupation of stations in the variant 3 as shown on the Figure 40 is approximately 45 trains in station hourly. the Highest number of trains in station is 60 trains.



**Figure 40.** Comparison of occupation of all stations for (var-1 and var-2)  
**Source:** [16]

With this kind of traffic organization, Sunja Station has become a hub station for transfer of passengers from all directions. The organization of passenger trains is based on Sunja as the main meeting point where all trains would arrive and depart at approximately the same time. A comparison of the number of trains in Sunja for variant 3 and variant 1 can be seen on Figure 41. Except from the difference in the number of trains per hour in the station, the importance is in the balance of the traffic through the railway station. In variant 1 there is around 1 or 2 trains

in the station every hour and in the afternoon that number jumps to 5 trains. In variant 3 there are always around 3 to 4 trains in station per hour. The traffic through the station is somehow balanced. The advantage of this organization is that the train station can optimize the work when it has approximately the same number of trains per hour. This is not the case with the current timetable where there is no train for one hour while the next hour there is peak occupation of the station.



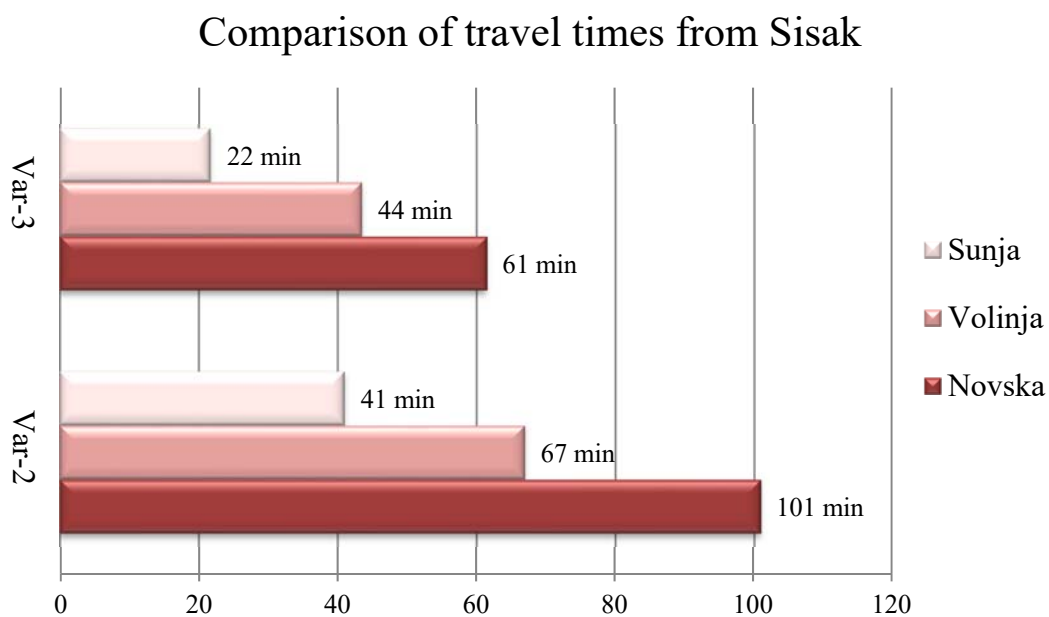
**Figure 41.** Comparison of occupation of railway station Sunja (var-3 and var-1)  
**Source:** [16]

**6.4. Travel times**

The development of the new organization and modification of infrastructure will ultimately have an effect on travelling times between stations. This can be evaluated in several ways but for comparative analysis, travel times with dwell times will be considered. The biggest impact

on the service, besides from the regular clock-phase timetable for passenger trains, is the improvement in speed. Finally, the goal of the new infrastructure is to be competitive to car transport and stimulate people to make the switch from private vehicles to trains and public transport. In this case, rail transport would lay the foundation for regional development and the mobility of people. An increase in speed to 120 km/h would mean shorter travel times between cities and villages and would have effect on energy consumption, sustainable development, the number of accidents that occur yearly on the roads in this region etc. This could rejuvenate the county and attract new people who would have the opportunity to work in cities and have a short trip to their homes.

A comparison of travel times between Sisak and the connecting stations is visible in the Diagram 3. The travel times are based on travel times for different passenger trains and are calculated by RailSys. The travelling time in variant 1 and variant 2 are the same because of the same infrastructure and the signalling system. The improvements in infrastructure have reduced all travel times significantly. For the trip between Sisak and Novska, travel time has been reduced by 40 %. The biggest reduction in the travelling time has been between Sisak and Sunja where the decrease of the travel time is 47 %. When considering the changes made in infrastructure this is a significant increase in speed considering that only the increase of speed to 120 km/h the implementation of automatic block signalling can reduce travel times on some sections up to almost 50 %.



**Diagram 3.** Comparison of travel times from Sisak  
**Source:** [16]

Travel times compared in Diagram 4 are based on the calculation from Google Maps and RailSys for the routes between railway stations. Google Maps determine travel routes between railway stations for the car travel times. The comparison of the travel times between train and car is based on infrastructure variant 3 and the current state and organization of traffic on the roads. The train has a faster travelling times by several minutes than the car apart from the travelling time between Sunja and Novska where the car is faster than the train by approximately 10 minutes. It is important to mention that travel between Sisak and Novska using Google Maps considers a part of the trip on the highway which increases the cost of travel. Not considering the price of the car and the monthly expenses for car maintenance and the cost of oil, the reduction in time means that people will have more time to efficiently use during travel. When travelling by train people have the opportunity to work on the train or have a short break compared to driving the car which requires full concentration during travel. Passenger trains can be part of an integrated traffic service in the region where it would be possible to travel with one ticket on trains, buses, bikes, electrical scooters and all other available transport options in order to secure a door to door service for a reasonable price.

Comparison of train and car travel times from Sisak

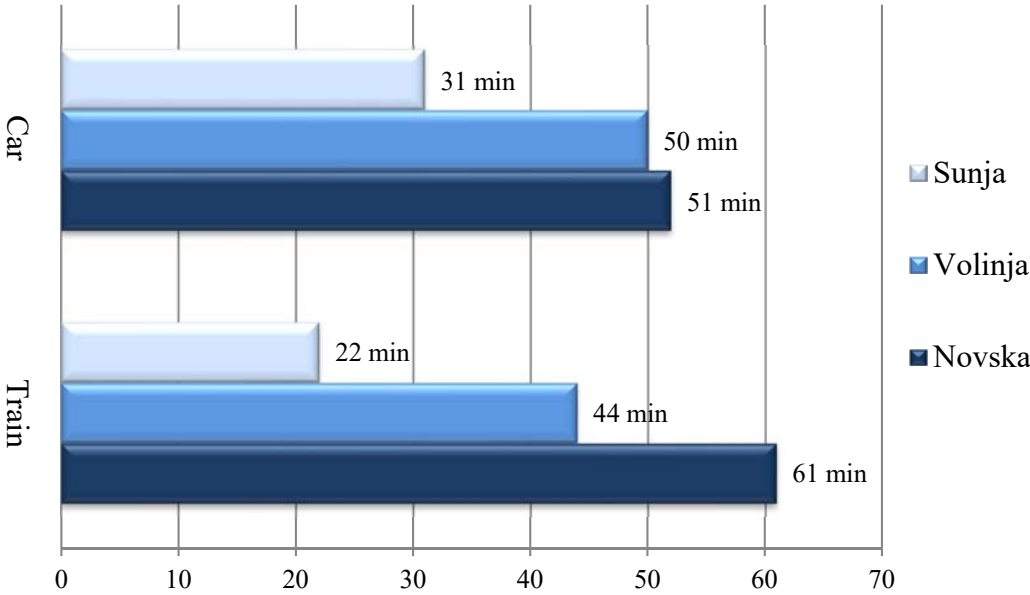


Diagram 4. Comparison of train and car travel times from Sisak  
Source: [16]

## 7. Conclusion

Optimization of the railway traffic is important part in a development of successful railway systems. Process of the optimization requires complex set of measures with the goal of finding best possible solution for any given infrastructure and traffic organization. Complexity of the process is demonstrated through number of interfacing elements that affect the railway system simultaneously. Development of technology and the fast-changing environment has oriented the railway system towards digitalisation and automatization in order to cope with the everchanging requirements and stay competitive with other modes of the transport.

The RailSys software is one of tools used for the optimization of the railway traffic. It is designed to model and recreate all sorts of the infrastructure and conditions on the railway track. RailSys is used for the optimization of the railway lines between Sisak – Sunja – Novska and Sunja – Volinja.

The railway lines with combined length of approximately 88 kilometres are connected in the railway station Sunja. Station Sisak, Novska and Volinja are used as a boundary for creation of the infrastructure model. Current infrastructure is limited by low travelling speeds and traffic regulation. This kind of the infrastructure has severely affected passenger service on this part of the network and cannot compete with the car and bus transport.

There are three timetable variants created in master thesis. Variants 1 and 2 of the timetables are created on the existing infrastructure with the difference in the traffic organization. The timetable variant 3 is based on the upgraded infrastructure model with improved signalling system. The data extracted from RailSys based on the different timetable variants is used for comparison of different elements. Variant 2 with the clock-phase timetable has significantly higher capacity utilization than variant 1 and provides much better passenger service. Organisational changes have enabled quality passenger service with just 5 trains which are circulating during the day. The timetable variant 3 with all improvements has significantly increased capacity of the lines while implementing higher number of trains. The clock-phase timetable is reduced to the 45 minutes between Sisak – Sunja – Volinja and to 90 minutes between Sunja – Novska.

A comparison of the timetable variants is based on the capacity occupation, track occupation, occupation of the railway station and travel times. The timetable variant 3 has notably higher

number of train runs, track occupation and capacity because of the reduced travel time and different signalling system in comparison to variant 1. This variant of the timetable is competitive to car travel and can be used as a foundation for the development of the railway traffic on these lines. The effects of these infrastructural and organizational modifications could stimulate regional development through green mobility. The influence and utilization of the railway network in this region can be induced through the organizational and infrastructural changes which could lay foundation for the future development of the region and the country.



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### A. Croatian railway network



Figure 42. Croatian Railway infrastructure  
Source: [8]



Figure 43. Loads on part of Croatian railway network  
Source: [8]



Figure 44. Traffic regulation on part of Croatian railway network  
Source: [8]

## B. Infrastructure details for railway stations

### B.1 Sisak

Name	Length (m)	Usable length (m)
<b>Passenger part of rail station</b>		
1	-	101
2	-	183
3	255	242/207
4	392,92	276/241
5	-	-
6	-	88
19p	-	301,80
20	-	17
1L, 2L, 3L, 4L, 7L, 8L, 9L, 10L, 11L, 12L, 13L, 14L, 15L, 16L, 18L	-	-
<b>Industrial part of railway station</b>		
Galdovo	1683	
Galdovo	3000	
<b>Freight part of railway station</b>		
1	735,52	438/403
2	825,80	478
3	943,03	706/671
4	943,03	780/745
5	888,31	674/639
6	590	572/537
7	714,35	560/520
10	155,70	111
11	106,68	64
13	162,07	162/127
14	143,15	61
16	-	-
19	-	101



20	-	-
<b>Industrial tracks inside freight part of railway station</b>		
16t, 17t, 19t, 21t, 22t	1508	-
Industrial track	621	-

**Table 2.** Track lengths for Sisak railway station  
Source: [9]

## B.2 Sisak Caprag

Name	Length (m)	Usable length (m)
1M	534,55	339,4
2	721,00	529,6/ 559,6
3	909,75	509,8/ 616,5
4	909,75	662,8/ 648,10
5	800,25	605,00/ 593,5
6	719,5	560,7
7	667,2	473,4
8	536,45	400,4
9	466,00	350,6
<b>ABS tracks in railway station</b>		
7		198
9		654
10		555
10a		505
10b		325
11		616
Lozionicki		105
VP4		255
Sajer		116

**Table 3.** Track lengths for Sisak Caprag railway station  
Source: [10]

## B.3 Sunja

Name	Length (m)	Usable length (m)
------	------------	-------------------

1		505
2		607/621
3		701/711
4		662/669
5		651/645
6		577/575
7		538/512
8		486
9		429
10		371
11		343
12		50
13	Closed	163
14		125
15	Closed	51
16	Closed	40
17	Closed	174
18		47
19	Closed	89
20		361
21	Closed	84
22	Closed	115

**Table 4.** Track lengths for Sunja railway station  
Source: [11]

#### B.4 Hrvatska Dubica

Name	Length (m)	Usable length (m)
1		630
2		635/623
3		646/632
4		647/633

**Table 5.** Track lengths for Hrvatska Dubica railway station  
Source: [12]

## B.5 Novska

Name	Length (m)	Usable length (m)
2	723,84	697
3	1085,14	658
4	1002,56	688
5	910,49	873
6	825,52	742
7	756,41	568
8	718,95	553
9	612,03	580,61
10	654,04	580,60
11	637,60	606,68
12	627,30	606,68
13	548,66	518,99
14	505,20	465,77
15	468,29	446,06
16	407,08	372,31
17	408,77	372,31
18	423,24	369,27

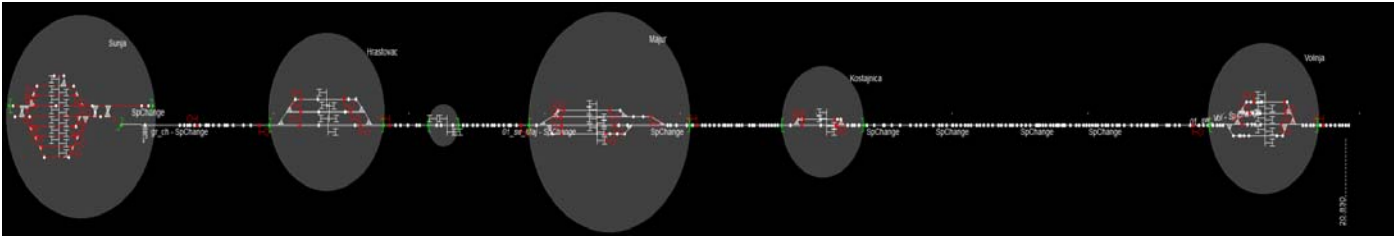
**Table 6.** Track lengths for Novska railway station  
Source: [13]

## B.6 Volinja

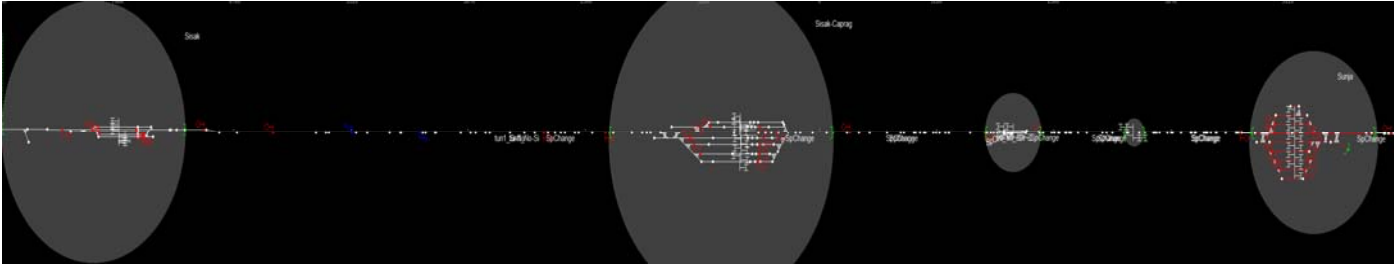
Name	Length (m)	Usable length (m)
1	640,42	640,42
2	652,06	652,06
3	652,06	652,06
4	752,06	752,06
<b>Stari Loziona</b>		
5	93,23	93,23
6	93,23	93,23

**Table 7.** Track lengths for Volinja railway station  
Source: [14]

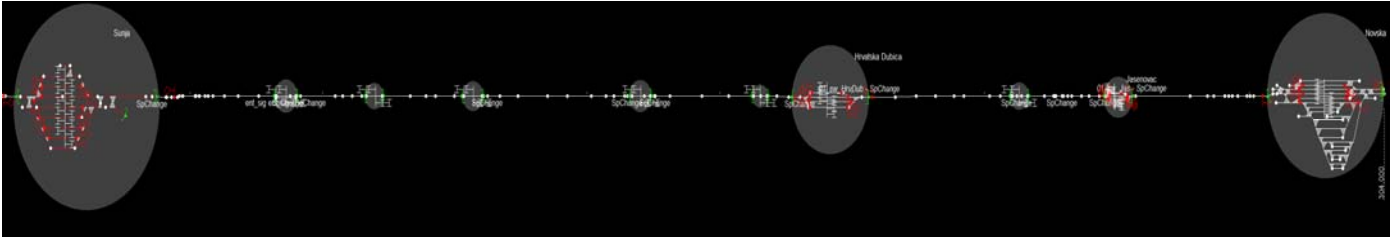
**C. Line model in RailSys program**



**Figure 45.** RailSys model of the Sunja – Volinja line  
**Source:** [16]



**Figure 46.** RailSys model for the part of the line between Sisak – Sunja  
**Source:** [16]



**Figure 47.** RailSys model for the part of the line between Sunja - Novska  
**Source:** [16]



University of  
Zagreb  
Faculty of Transport and Traffic  
Sciences  
10000 Zagreb  
Vukelićeva 4

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