Effective parameters for capacity assessment of an upgraded railway: the case study of Ghana Western Line

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Abstract

The most critical issues in the railway transportation are capacity and infrastructure. Improving infrastructure has effect on the capacity. But investment in infrastructure always is the most expensive way to increasing the capacity. In this thesis the station distant, choosing equilibrium speed and effective of two separate tracks for opposite traffic compared.

According to this criteria capacity is not only important in operation period time but also it is important for the infrastructure construction. It is also the most important issue for Entrepreneur and investor because they can have more capacity with low investment and more benefit. Furthermore, it is important for prosperity of the country. So, this issue is important from both side economical and financial evaluation.

All in all, according to this introduction in this dissertation capacity as a most critical parameter in railway examined. For this reason, OpenTrack simulators exploited for comparing the factor and the most critical parameter determine by Taguchi statistical theory . At the end the most critical parameter is specify the number of tracks.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

Chapter 1
Introduction

1.1 RAILWAY TRANSPORT SYSTEM

Set of infrastructure, vehicles and services allowing mobility of persons and goods to perform social and productive activities of society. Fixed plants (infrastructures), rolling stock (vehicles) and services will be ensuring mobility of passengers and goods.(1)

However always the railway infrastructure cost in comparison to road infrastructure is too high, high capacity of railway and less traffic problem can compensate this issue. So meanwhile the basic and the last part of each travels for freight and passenger mostly done with road but railway network help to have more reliable network transportation in country. So the fundamental needs for progressing and passing from developing condition to developed condition for each country is making infrastructure. The next step for decision maker is always compromise between cost, environment impact, and reliability. So because of these factors most of the countries are getting so enthusiastic to railway transportation. Furthermore, it can be a safe and efficient mode of transportation mode.

As the most critical part of the transportation always is demand and supply, capacity play a vital role for cost and benefit analysis. So cognition of the effective parameters on capacity can help engineers to design line with high performance for users. Meanwhile it can make project more attractive for government and investors.

1.2 CAPACITY OF RAILWAY

The International Union of Railways (UIC) defined railway capacity in 2004 as: “Capacity as such does not exist. Railway Infrastructure capacity depends on the way it is utilized”. However, UIC 406 defines railway capacity as “the total number of possible paths in a defined window, considering the actual path mix or known developments respectively…”.(2)

Capacity consumption on railway lines depends on both the infrastructure and the timetable. But in this thesis I will mostly concentrate in infrastructure effect.

Railway capacity is complex to be understood, however it is essential for determining the traffic volume that can be moved over a rail system and the level of service and reliability that can be expected. The practical capacity in relation with the theoretical capacity and the anticipated reliability is presented in the following diagram.(2)

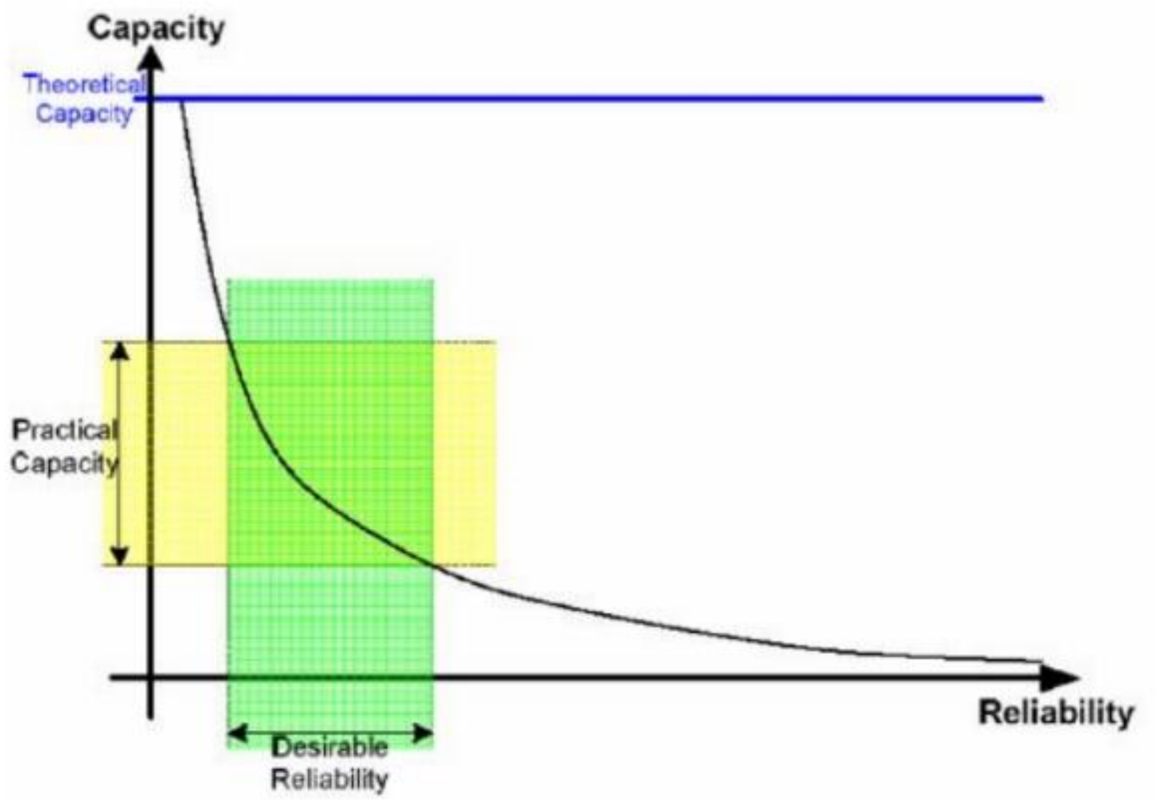

Figure 1: practical capacity of railway line (TEN-CONNECT,2010)

1.3 AIM OF DESSERTATION

In this thesis, the most critical parameters that affected to the capacity of the railway examined (speed, number of tracks, and station distance). These factors will be the tree factors examined and simulate with OpenTrack simulator to analyze the most critical parameters between them.

Western-line Ghana railway is a pilot study I will simulate in this dissertation. I chose this railway because I designed some part of this project in the TEAM engineering. This railway line is located in Ghana, Ghana is a rich natural source country that need infrastructure for improving and progressing the country. The total Ghana rail network extends for 939 kilometers of routes (1,200 km of tracks, including double track sections), all located in the southern regions; it is made up of the Western, Central and Eastern-Lines. The country’s railway operates through various cities, major and small towns.

Chapter 2
Literature Review

2.1 CAPACITY ISSUES AND CONCEPT

Railroads have absorbed huge increases in both train-miles and ton-miles in recent years. Capacity is created (or destroyed) by a host of factors, all interrelated. While tend to think of capacity as an infrastructure issue, rolling stock, motive power, and employees and operating strategies (size of trains, speed of trains, timing of trains, etc.) is all part of the equation.(3)

The capacity conditions in railway traffic are fundamentally characterized by the very limited overtaking possibilities of the individual trains. This property implies that the travel time for one train may influence the travel time of other trains, and that the travel times will therefore depend on the actual timetable. Railway traffic can be compared with a long bus lane where transit busses must only overtake at selected stops. This lack of continuous overtaking possibilities gives rise to many dependencies between the individual train departures. These dependencies are partly seen during the planning phase, where they have a great influence on the design of the timetable, i.e. the establishment of the departure and travel times of the trains, and partly during the operation process as delays spread to other trains.(4)

Capacity can be defined as the capability of the infrastructures to handle one or several timetables.(4)

All transport systems are characterized by consisting of a well-defined "infrastructure", some transport units and a set of "rules of game". When these 3 concepts are interacting, we talk about traffic. Each transport mode has its own characteristics, both with regard to infrastructure, transport mode and the "rules of games". Since the interaction between these 3 concepts is fundamental importance for the capacity conditions, the different transport modes will have different properties in this field.(4)

According to the laws of mechanics, when talking about traffic, capacity is often defined as volume multiplied by distance per time unit. In physics, capacity is thus defined as the work produced during as the work produced during a time unit [Nm/s]. This also applies to railway operation facilities, where "work" can be defined as transport units through an operations facility. If the "volume" consists of travelers or good, you talk about traffic capacity. It is persons multiplied by distance per time unit [pkm/day] or tonnage carried multiplied by distance by time unit (trains or wagons). The transportation capacity is the transport units multiplied by distance per time unit (train-km/day).(4)

The capacity of an infrastructure does not only depend of its design, but also on the properties of the trains that to use it. Furthermore, the order in which the different train classes are operated on the infrastructure also has a major impact on the capacity. The capacity of a line can thus change without the infrastructural conditions being changed. Therefore, a plan of operation will not be sufficient to describe the exact capacity. It requires an actual timetable. Capacity can be described at the following 3 level, the operators' required capacity, technically possible capacity, and capacity rendered at the actual capacity conditions. (4)

2.2 POSSIBLE CAPACITY

The possible capacity of an operations facility is its ability to obtain a certain capacity under the assumption of an unlimited capacity demand with a given operational structure. The structure of the capacity demand (order and transport unit properties) is important when studying the possible capacity. Changes in the structure of the capacity demand thus lead to different possible capacities.(4)

The lower possible capacity compared to the maximum capacity is not due to less requirements to the operations facilities, but only as a result of less reliability and accessibility to infrastructure rolling stock and crew.(4)

The capacity of an infrastructure facility is the ability to operate the trains with an acceptable punctuality.(4)

2.3 THE OPTIMAL FIELD OF CAPACITY

The optimal field of capacity of an operation facility is the one where the attainable benefits are bigger than the necessary costs that lead to capacity. The optimal capacity point is the one where the difference between the benefits and the costs is biggest. The costs, which depend on the load, are shown in figure 2. Figure 2 shows a strongly progressive shape for the costs as a function of the load. The progressive shape is due to the fact that the queuing time which can be estimated.(4)

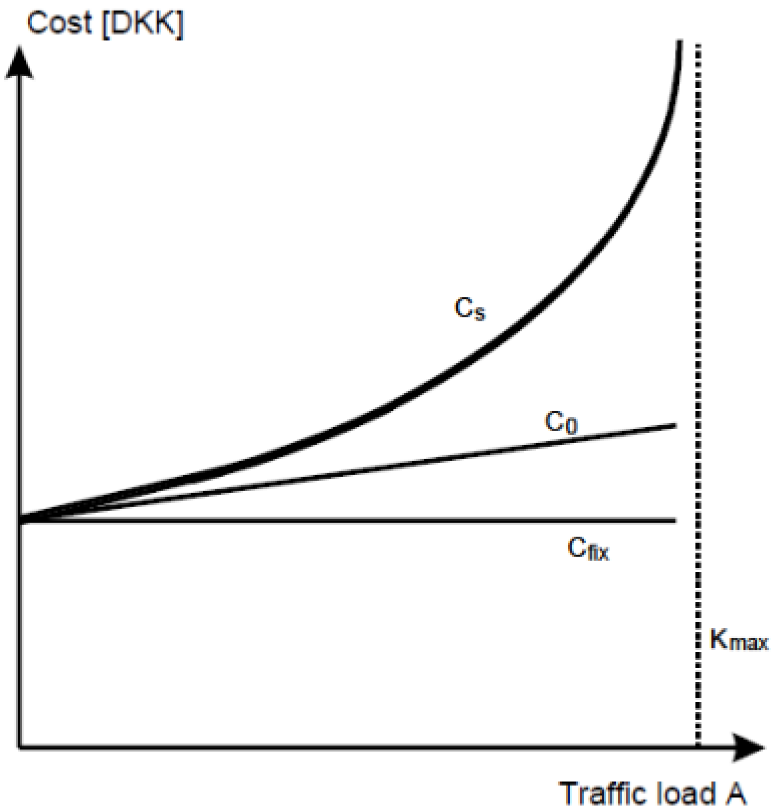

Figure2: the cost function

The total operational costs C_0 can thus be expressed as the sum of the fixed costs C_{fix} (not directly related to the operation) and the costs directly related to the operation. (4)

2.4 CAUSES OF DELAY

One of the most important quality indicators of public transportation is punctuality. Deviations from schedule reduce the level of service.(5)

Efficiency and level of quality can be improved by minimizing the “gaps” between the elements of the quality loop (Heinitz and Fritzlar, 2013). Provision of passenger information significantly affects the quality perception, which helps smoothing the possible quality “gaps”.(5)

According to the study (Tu et al., 2012), in regards of mode choice influencing factors, 1-minute reduction in the standard deviation of travel time is equivalent to 2 minutes’ reduction in travel time. Based on risk analysis, a common-used travel time reliability model has been also devised. In the mentioned study, probability and severity of incidents was determined as well. The topic of study (Beaud et al., 2012) is the reliability of estimated travel time. It was approximated in two different ways: the methods of mean-variance and specific coefficients. Two definitions have been introduced for the value of reliability: the maximum amount of money over the basic fare that passengers are willing to pay in order to avoid uncertainty (meanwhile travel time does not change), the maximum additional travel time that passengers are willing to accept in order to avoid uncertainty.(5)

The most frequent reason for delay is guaranteeing connections. Delays above average value have been caused by other railway companies and in case of extraordinary weather conditions.(5)

The National Audit Office in United Kingdom reported that there were about 800,000 delays on the British national rail network during 2006–2007. This led to 14 million train-minutes of delays, which cost the passengers about £1 billion in lost time.(6)

Delay is the extra time it takes a train to operate on a route due to conflicts with other traffic. Reduction in delay is often used by the railroads to calculate the benefit of a project or operational change. However, the specific factors that cause these delays are not well understood. (7)

It is widely acknowledged in the transportation economics literature that more reliable transport time constitutes an economic benefit. In the presence of unreliability, individuals and firms adjust by taking costly measures like departing early or keeping a safety stock of goods. The 'cost' of train delays is therefore the foregone benefits that could have been achieved if all trains were running on time.(8)

Unscheduled delays can be caused by numerous events including: mechanical failures, malfunctioning infrastructure, weather conditions, excessive boarding times of passengers, accidents at highway-railroad grade crossings and so on. (7)

Delays to one train can lead to a cascading effect of delays to other trains. As a route nears its theoretical capacity the probability that a delay will lead to subsequent delays increases, while the ability to recover from these delays decreases.(7)

Class 1 railroads are expected to face increasing capacity constraints due to long-term projections of growth in both freight and passenger traffic. In order to accommodate this new traffic railroads will need to modify operational practices and build additional infrastructure. Railroads are increasingly using simulation to plan these changes and projects. One of the primary outputs from these simulations used by railroads as a metric for capacity and efficiency is train delay. Delay is influenced by a number of factors and its relationship to capacity is indirect. Simulations of railroad operations were performed under a variety of volumes and traffic mixtures and the delays categorized by source and conflict. The results offer better insight into the different factors that contributing to train delay. Better understanding of this capacity metric will enable railroads to conduct more effective capacity planning by focusing on alternatives that will provide the greatest reduction in delay.(7)
The maximum capacity of a route is dependent on operational decisions by the railroad. When determining capacity each railroad determines the maximum tolerable

delay based on the traffic mix, route geography and service requirements. Greater tolerable delays will increase the capacity of a route, but decrease the level of service and reliability (figure 3).(7)

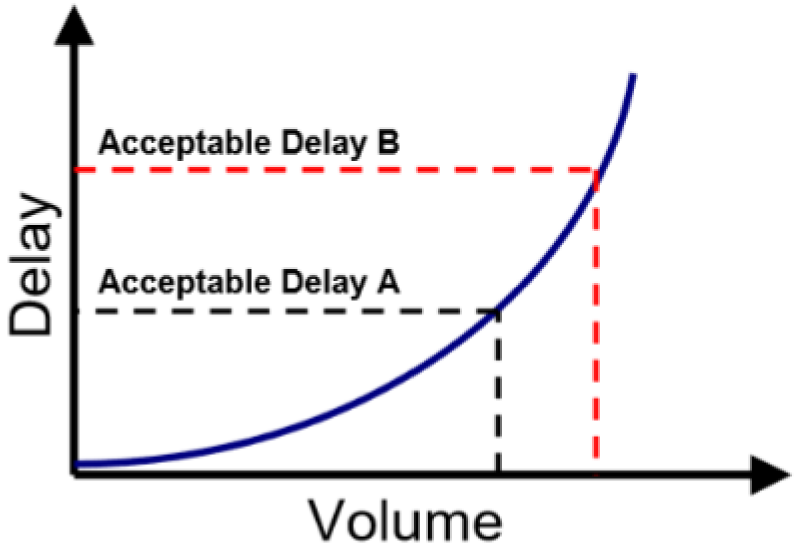

Figure 3: Maximum volume based on maximum allowable delay

Gibson et al. (2002) find that the level of capacity utilization usually contributes to congestion delay using a simple regression model on a number of routes in the UK. Both variables used in this study are subject to scrutiny. The dependent variable, ‘‘reactionary delay”, is not clearly defined and authors describe as ‘‘not easy to measure”. The lone independent variable, capacity utilization, is the ratio of a ‘‘squeezed time table” with minimum train headway between all trains over an actual time table. This definition of capacity utilization ignores the impact of opposing traffic. Most importantly, the econometric specification used in Gibson et al. (2002) may suffer from omitted variable bias; clearly, there are numerous key variables other than capacity utilization that affect train running times. The study simulates the congestion effect of heterogeneous train speeds, but does not attempt to estimate this impact econometrically. We seek to extend this line of research with a more holistic and useful set of easily measured variables to evaluate whether econometric methodologies can contribute to the understanding generated from the optimization and simulation research. Further, the accuracy of train congestion prediction is evaluated, the contributions of train heterogeneity to rail congestion are identified, and the average congestion delay of incremental train traffic is estimated.(9)

Railroads establish train classifications which receive varying horse power ratios (HPT) in order to achieve expected running times. The higher HPT is correlated with generally higher dispatching priorities for faster trains.(9)
Figure 4 provides a schematic of the causal model. The most easily measured train performance statistic is train running time (TRT). TRT is a function of the trains free running time (FRT), and congestion-related delays (CRD). Total running time (TRT) is

predicted by isolating FRT and CRD determinants, where TRT= FRT+ CRD. By definition, causal factors for FRT and CRD are orthogonal to each other.(9)

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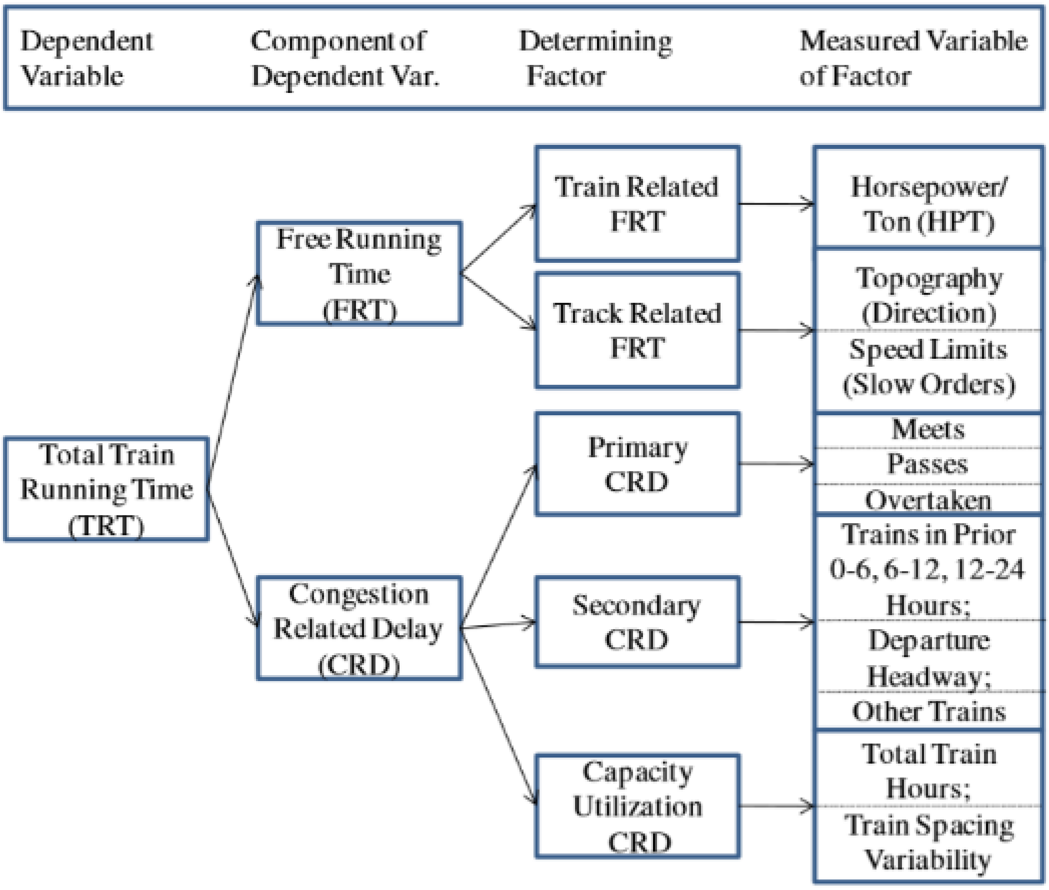


Figure 4: Schematic of casual total running time model.

FRT is the theoretical minimum run time for a train on a track segment from the physics of the train operations with no impedance from other trains from contention for track resources. Free running time (FRT) is governed by two determining factors: Train factors (HPT) and rail factors (topography and speed limits). FRT factors are estimated only to specify the base component of TRT; additional time is CRD.(9)

CRD is the component of TRT above FRT and is of primary interest in this study. CRD is split into three factors: Primary, secondary and capacity utilization factors. Primary delay is the result of interference experienced directly by a train (a meet or a pass); secondary delay is the result of interference of other trains that indirectly influence the train (by creating congestion ahead of a train). Capacity related factors include capacity utilization and train departure variability which reduces capacity. Table 3 specifies independent variables chosen to capture FRT and CRD factors as defined in the causal model (figure 3), describes their source, and their hypothesized sign.(9)

Primary, secondary and capacity utilization related CRD factors and resulting explanatory variables are established based on rail intuition and expert opinion, and from the literature in this area (Vromans et al., 2006; Gibson et al., 2002; Krueger, 1999; Prokopy and Rubin, 1975), as well as practical factors such as availability and reliability of recorded data. The direct and in direct train-specific CRD variables are depicted in Figure4. The most commonly used CRD factor is daily train count (e.g., Krueger, 1999; Prokopy and Rubin, 1975). However, a simple daily train count does not differentiate whether a train has a direct or indirect effect on a train. As discussed by Vromans et al. (2006), some trains have a ‘‘secondary delay” from trains that do not directly come in conflict for track resources but cause generally congested conditions, while others have a ‘‘primary delay” from meets and passes. The size and type of effect in each case is logically different likely to be quantifiably different, thus the two effects are separated. In order to capture secondary delay only, only trains that have run in the period prior to the train in question are counted. The calendar date designation for train counts is inappropriate for a number of reasons. First, a count based on a calendar date designation is arbitrary; the logical period defined by the train’s entrance into the district is more appropriate. Second, trains on the same date may follow the train in question rather than precede it, nullifying their congestion effect on the earlier train. By counting only trains prior to the train in question, the congestion effect is unidirectional; earlier trains create congestion for later trains, not vice versa. Only trains that have completed the traversal of the entire track segment moving in the same direction as the train in question before the train begins its traversal are counted to assure only secondary (no primary) impact (i.e., no redundancy with passes).(9)

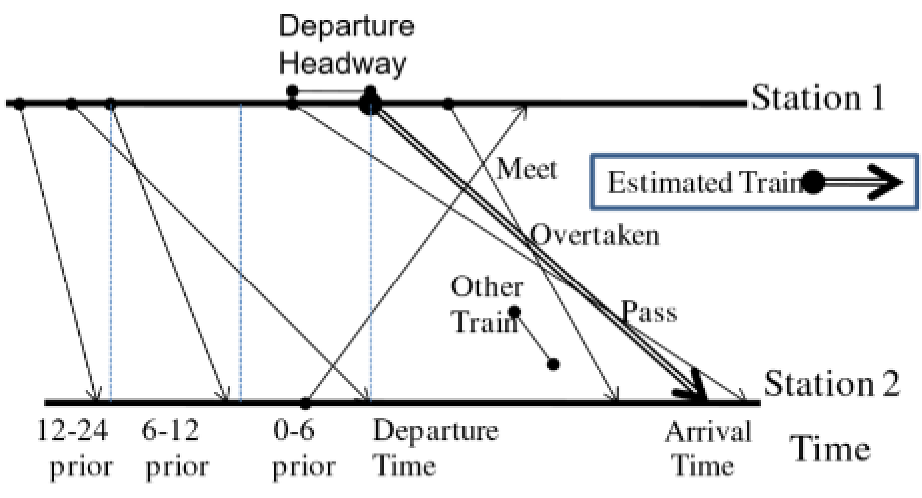


Figure 5: A string line schematic of train – specific CDR independent variables.

Vromans et al. (2006) suggests that in their model, arrival headway (at destination) play a bigger role in their measure of congestion delay. This measure focuses only on same-direction trains without passing; headway is meaningless for opposing trains. Arrival headway is a result of the heterogeneity of train speeds as one train catches up with or falls behind another; thus cause and effect can be confused. Large arrival headway could be the result of a slow moving train (large FRT), or a fast moving train that just passed another (fast FRT). In either case, it represents the congestion facing the train on the next district more than that on the current district. Arrival headway is only sensible in the case where no overtakes occur on the district (generally not the case in practice), so it is excluded from the model. (9)

Primary delay comes as a result of direct contact of two trains, through meets and passes. Meets are a function of timing and volume of opposing trains. The meets variable is calculated as the total the number of opposing trains that start or end on the segment at the same time as the train in question. Meets can have either no impact on CRD (a running meet, say, on double track), or cause a delay. The sign on the number of meets is hypothesized to be positive. Train speed heterogeneity is a widely recognized cause of CRD because it results in train passes and overtakes. Generally, the literature expects non-conforming trains (that is, trains with considerably different FRT than the rest) to cause more congestion (Harrod, 2008; Gibson et al., 2002). Thus, the actual impact of train speed depends on the general mix and timing of train speeds on the district, which varies from district to district. Krueger (1999) includes measures of traffic levels variability in addition to traffic levels. Attempting to capture a measure of heterogeneity, Krueger includes a ‘‘Speed Ratio”, which captures the ratio of the fastest to slowest trains but it is based solely on the maximums and minimums and does not necessarily capture full flavor of the train heterogeneity and traffic mix.(9)

A second capacity utilization factor comes from Vromans et al. (2006) that suggest train spacing variability (the inconsistency of arrival and departure intervals) as a contributor to congestion delay. This suggestion is logical, given variable arrivals will generally reduce available capacity put and increase the flow time. This work hypothesizes the uniformity of the headway (or conversely, the ‘‘bunching”) of trains is a major contributing factor to congestion. The ‘‘Sum of Headway Reciprocals” measure proposed by Vromans et al. (2006) includes a weighted average of the arrival and departure headways across all trains in the district. The sign of this ‘‘train spacing variability” variable is expected to be positive; that is if there is more bunching of trains, the sum of headway reciprocals goes up, and congestion delay goes up.(9)

2.5 TRAFFIC REGULARITY

The possibility to improve the capacity of railway lines, within the regularity levels fixed by the railway undertaking that manage the transport service, may be verified, or at least estimated with good approximation, during the planning phase, by railway operation simulation models. The models, to be useful, should simulate the process with all boundary conditions imposed by infrastructure, signaling and control systems. Moreover they should be applied on every railway plant, i.e. they should have high flexibility in the railway system representation.(10)

2.6 IMPACT OF SIGNALING

The dependability or RAM (Reliability, Availability and Maintainability) parameters are the most important elements that allow to estimate the Life Cycle Cost (LCC) of a system and to forecast performances during operating conditions. In the field of railway transportation, conventional measures, such as the mean delay of the train, or the Service Dependability (SD), can be profitably used to estimate the overall system behavior taking into account the presence of failures.(11)

2.7 RAILWAY INFRASTRUCTURE

Railway traffic has increased over the last decade and it is believed to increase further with the movement of transportation from road to rail, due to the increasing energy costs and the demand to reduce emissions. The key goals of the White Paper 2011 for the European transport system include; a 50 % shift of medium distance intercity passenger and freight journeys from road to rail and waterborne transport, and a 60 % cut in transport CO_2 emissions by 2050 (EC, 2011). At the same time, the crude oil output reached its all-time peak in 2006 (IEA, 2010). The available capacity of the railways has to be enhanced in order to meet these new demands in transportation. As railway infrastructure and their components have a long life span, their management requires a long term sustainable strategy. Ongoing technical and economic assessments are necessary to optimize the performance of railway infrastructure and receive the return on investment (ROI) in a manageable timeframe. Long-term asset management objectives and strategies are developed to steer the operation and maintenance activities in the right direction. These objectives need to be broken down into quantitative operation and maintenance objectives to achieve a high level of robustness, punctuality and capacity within the operational budget, at the lowest life cycle cost, with no or an acceptable level of risk.(12)

2.8 ESTIMATE RAILWAY CAPACITY

Usually capacity is described as a number of trains passing the district in some time. However the capacity cannot be expressed as exact value calculated according to a formula when railway network is concerned. Network capacity highly depends on the traffic schedule and traffic consistence. Different schedules create different network capacity. Every schedule requires different investments into infrastructure (Harrod 2007; Abril ET al.2007). Residual (reserve) capacity variation is subject to the traffic consistency (e.g. mixed passenger and freight train traffic) (Landex 2008).(13)

Capacity K in introduce by this formula $K=q_{max} . n$, where q_{max} is th maximum traffic intensity and n is the number of train paths. The traffic intensity calculate by this formula $q= D . v_{avg}$, where D is the traffic density. As it appears from the formula, the traffic intensity q does not only depend on the average speed, but also the actual density. The maximum traffic density will depend of the speed , braking and safety systems. (4)

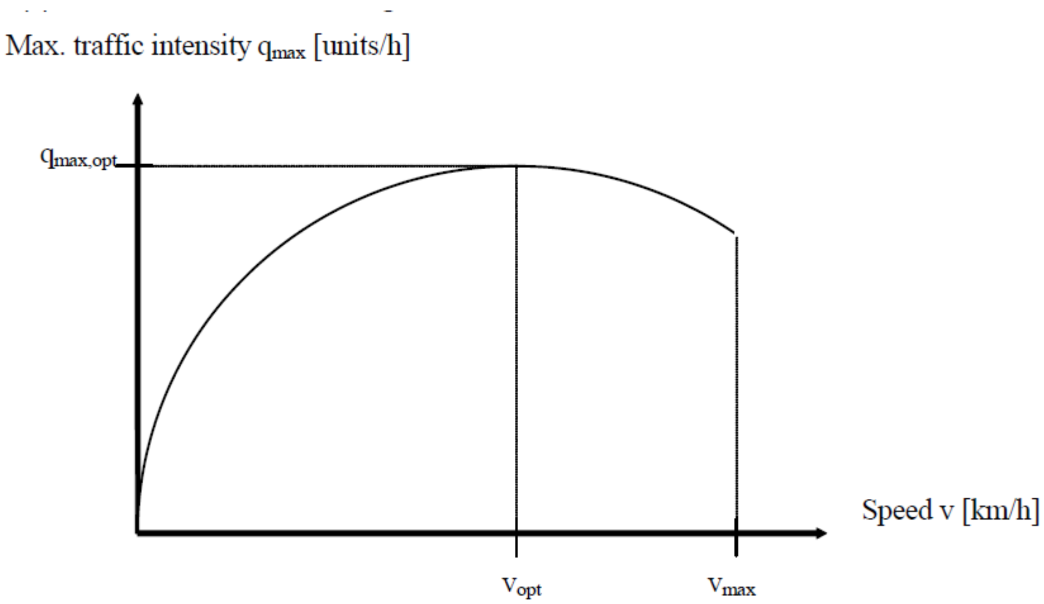


Figure 6: Maximum traffic intensity q_{max} as a function of the speed v

In the early days of railways, railway capacity was more or less a question of whether or not there were railway tracks. However, as the railway system grew and more trains were operated, lack of capacity was experienced. These capacity problems were (partly) solved by doubling railway tracks and extending the railway stations—and in some cases by building completely new railway lines and/or stations. Construction work solved many of the capacity problems, but technological development (e.g. signaling technology) also played a role.(14)

High capacity consumption results in a high risk of (consecutive) delayed trains as there is less buffer time between trains. These delays propagate differently depending on the type of operation (double track or single track operation and homogeneous or heterogeneous operation). If a train is delayed, so, too, are the passengers. The length of delay passed on to the passenger depends not only on the train's delay but also on the possibility of using other trains. In some cases, delayed trains may even be an advantage to the passengers, e.g., if passengers can catch an earlier train due to the delay.(14)

Lack of capacity means, that it is not always possible to create the desired timetable. It may be necessary to homogenize the operation, for example, by slowing down the fastest trains and/or giving the trains additional stops. This is denoted scheduled waiting time and can be regarded as scheduled delays because the trains (and the passengers) could arrive earlier as in the case of the "desired" timetable.(14)

It is relatively straightforward to determine the capacity on roads: it is normally determined merely as vehicles per hour. Capacity on railways is, however, more difficult to determine because the capacity depends on the infrastructure, the timetable and the rolling stock (Kaas 1998b).(14)
Examining the road travelers' capacity is also relatively straightforward as it is possible to multiply the number of cars per hour by the average number of travelers per car (or alternatively the number of seats per car). The capacity of freight on roads can be estimated, in a similar way to the travelers', by multiplying the number of Lorries with their maximum permitted loading capacity in tones (or alternatively their average load in tones). For public (passenger) transport it is, however, more difficult as public transport modes have a larger number of seats per vehicle, which is why a more discrete function is required, figure 7.(14)

The determination of travelers' capacity is further complicated by the different types of vehicle that can be chosen for the same operation, e.g., a bus service can be operated with a “normal” 12-metre-long bus or an 18-metre-long articulated bus that can carry more passengers. For train operation it is also possible to operate with more units per departure1 (figure7) or even combine train units with different seating capacities.(14)

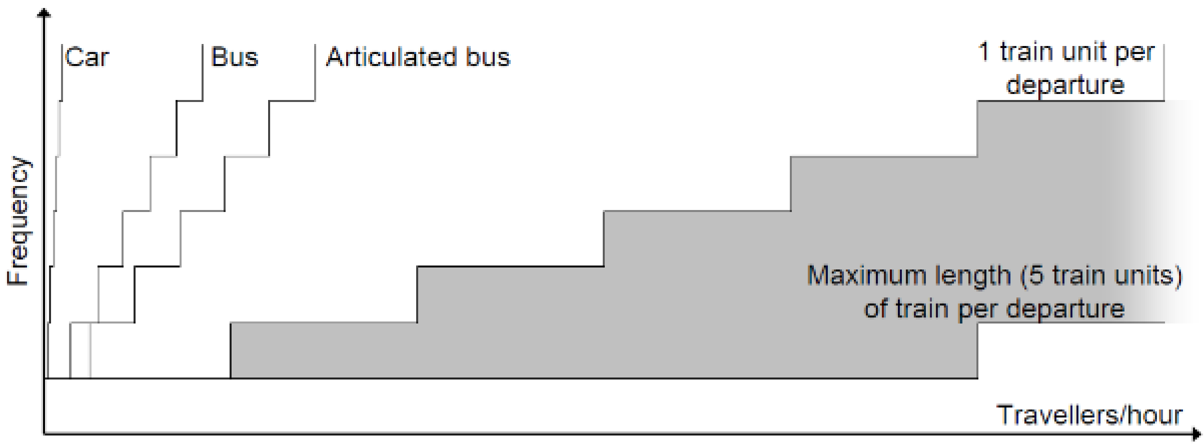


Figure 7: Correlation between frequency and number of available seats. Inspired by (Hansen 2004b, Landex, Kass & Hansen 2006)

Railway capacity is further complicated by the fact that the running characteristics and the length of the train affect how many trains it is possible to operate per hour, because slow trains and long trains occupy the block sections for a longer time and might have lower acceleration rates. Although capacity of travelers is an important issue in railway operation, this chapter (and the following) considers the capacity only in terms of how many trains can be operated in a given time period.(14)

Although railway capacity is complex to understand, it is essential for determining the amount of traffic that can be moved over a rail system and the degree of service and reliability that can be expected. Furthermore, the effective management and utilization of assets is becoming more important as railways strive to reduce costs, improve service and handle increased traffic (Krueger 1999).(14)

Railway capacity is difficult to define because there are several parameters that can be measured, figure 8. The parameters seen in figure8 (number of trains, stability, heterogeneity and average speed) are dependent on each other. This further complicates the definition of railway capacity.(14)

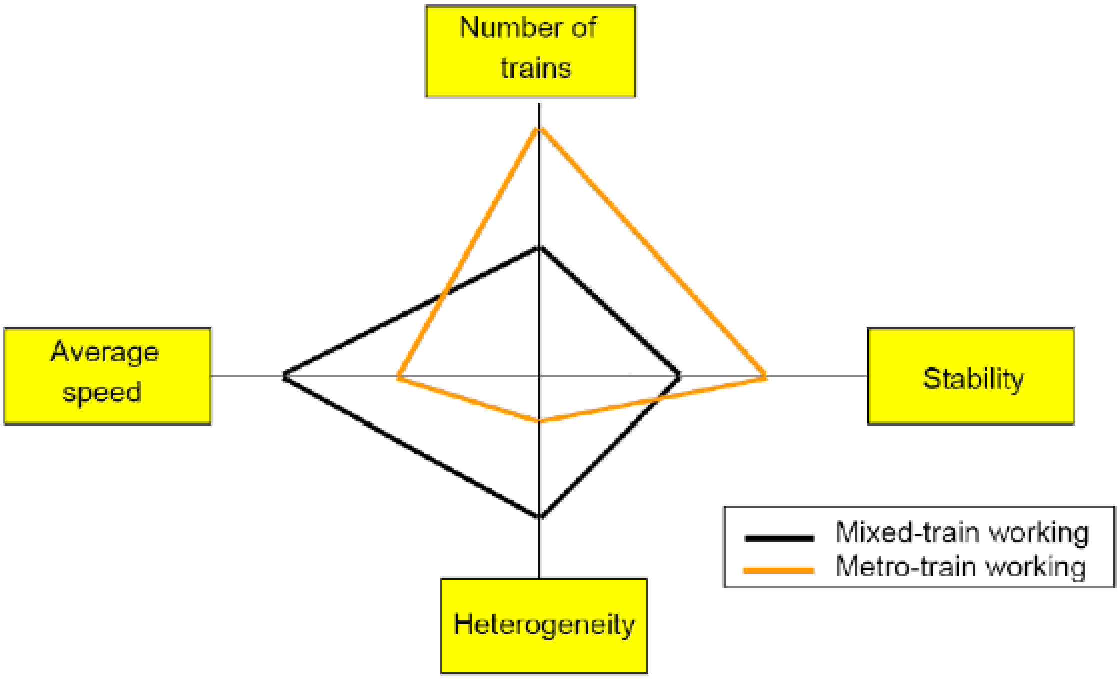


Figure 8: The balance of railway capacity (UIC 2004)

Figure 8 shows that capacity is a balanced mix of the number of trains, the stability of the timetable, the level of average speed achieved and the heterogeneity of the operation. It may, for instance, be possible to satisfy a market demand for a high average speed by having high heterogeneity—a mix of fast Intercity Express, Intercity and slower Regional trains serving all stations. However, the consequence of having high average speed and high heterogeneity is that it is not possible to operate as many trains with a high stability (punctuality) as when all trains are operated with the same speed and stop pattern. If there is market demand for operating more trains, it may be necessary to have a less mixed operation and thereby have a lower average speed (assuming that the fast trains are adapted to the slower trains) as it is known from, for example, metro systems.
It could be argued that the description of railway capacity presented by the UIC includes only the timetable and not the infrastructure, the rolling stock or the quality of service. However, both the rolling stock and the infrastructure are implicitly included because they are important parameters for the timetable, while the quality is described by the stability (punctuality), the number of trains (frequency), the average speed (travel speed) and the heterogeneity (the mix of trains).(14)

Due to the interaction between the infrastructure and the timetable, and that the capacity depends on the timetable, it is difficult—or even impossible—to define railway capacity in a consistent way.(14)

Therefore, railway capacity has been defined differently over time, e.g.:

• Railway capacity is the ability of the carrier to supply as required the necessary services within acceptable service levels and costs so as to meet the present and projected demand for such services (Kahan 1979)

• The capacity of a railway line is the ability to operate trains with an acceptable punctuality
(Skartsæterhagen 1993)

• The theoretical capacity is defined to be the maximal number of trains that can be operated on a railway link (Rothengatter 1996)

• The capacity of an infrastructure facility is the ability to operate the trains with an acceptable punctuality (Kaas 1998b)

• Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan (Krueger 1999)

• The only true measure of capacity therefore is the range of timetables that the network could support, tested against future demand scenarios and expected operational performance
(Wood, Robertson 2002)

• Capacity can be defined as the capability of the infrastructure to handle one or several timetables (Hansen 2004b)

• Capacity is defined as the maximum number of trains which can pass a given point on a railway line in a given time interval (Longo, Stok 2007)

• Capacity may be defined as the ratio between the chosen time window and the sum of average minimum headway time and required average buffer time (Oetting 2007)

• The capacity of the infrastructure is room on the track that can be used to operate trains
(Jernbaneverket 2007)

• The number of trains that can be incorporated into a timetable that is conflict-free, commercially attractive, compliant with regulatory requirements, and can be operated in the face of anticipated levels of primary delay whilst meeting agreed performance targets (Barter2008)

The above definitions of railway capacity show (although many definitions are alike) that there is great variation in how railway capacity can be defined. A reason for this variety is that most definitions of railway capacity are defined nationally or in connection with a specific project. Common to the definitions is that the railway capacities depends on the railway infrastructure and the timetable and, thereby, implicitly on the rolling stock used, figure 9.(14)

Railway capacity depends not “only” on the rolling stock, the infrastructure and the timetable sometimes the capacity is reduced due to processes in the operation such as time consuming departure procedures or external factors such as the weather and problems with the rolling stock. Processes can be procedures at departures, staff schedules, many passengers at the stations etc., while the external factors can be, e.g., weather conditions, breakdowns and accidents. Common to the processes and external factors is that it is not possible to predict their influence on the operation; nevertheless, attempts are made to minimize this influence by, for example, adding time supplements in the timetable.(14)

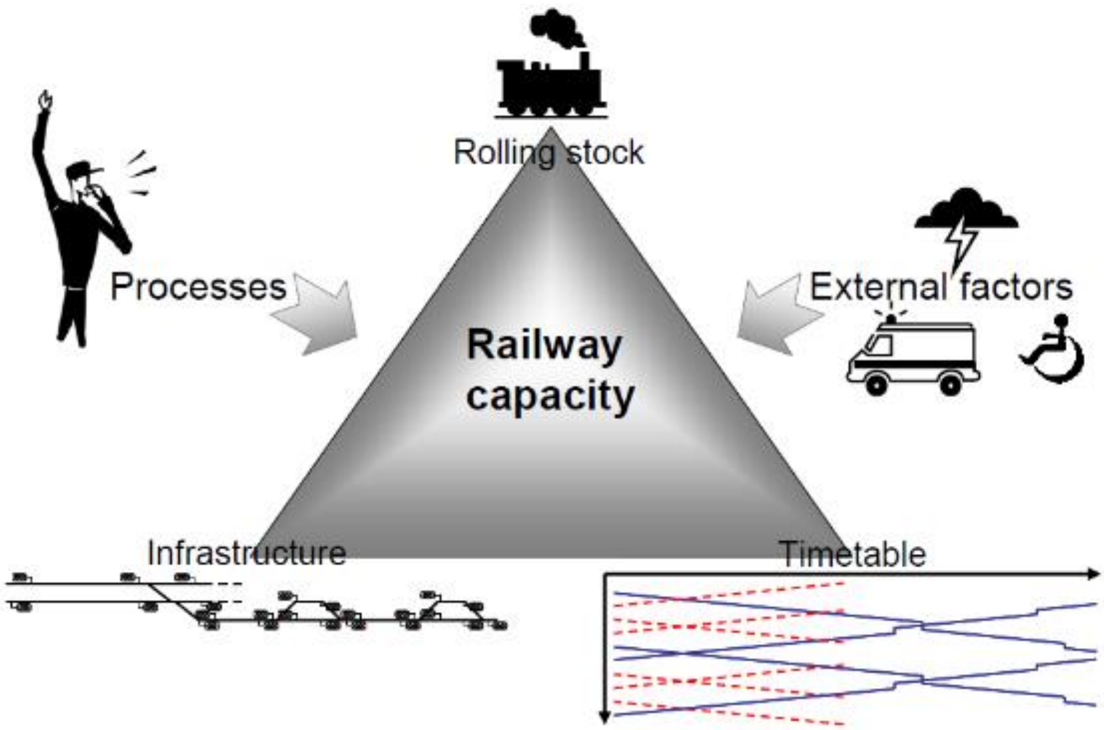


Figure 9: parameters in railway capacity

The definitions above (summarized in figure9) are not commonly accepted, although the definitions in themselves are correct. However, using all the capacity to operate trains will have (due to almost no buffer times) result in a high risk of consecutive delays and less attractive timetable. Therefore, the quality of the operation is important figure10.(14)

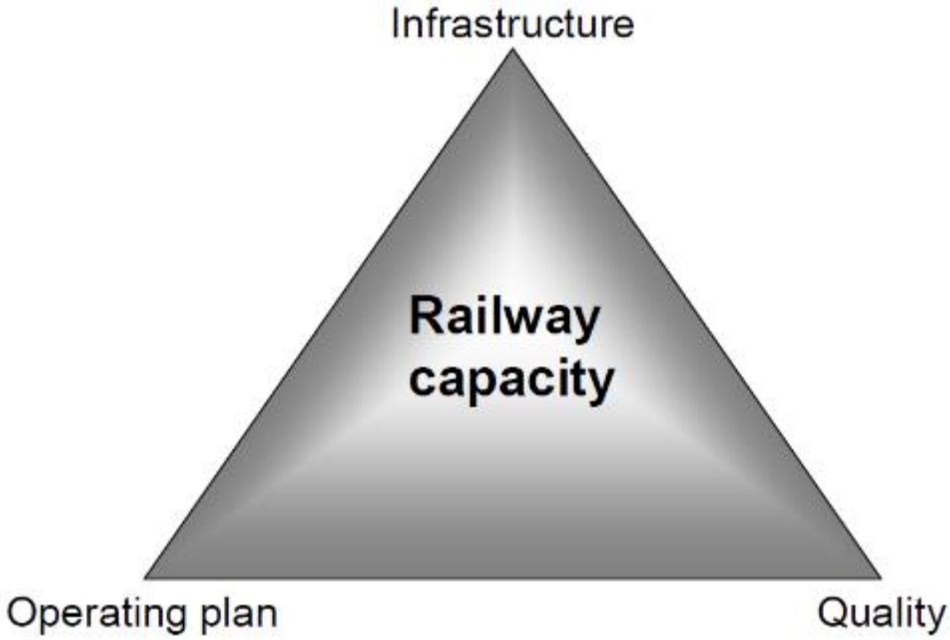


Figure 10: Definition of railway capacity based on (UIC 1996)

It could be argued that the definition of railway capacity presented in figure 9 includes only the operating plan and not the rolling stock as in the earlier described definitions. However, the rolling stock is implicitly included as it is an important parameter of the operating plan.(14)

According to (Abril et al. 2008) the capacity of railway systems is understood and analyzed in many ways. This is because capacity should be considered during the whole planning horizon. Furthermore, the railway capacity is viewed differently from the market, infrastructure planning, timetable planning and operations as stated by the UIC (UIC 2004).(14)

As capacity is an important factor on all levels of planning railway infrastructure and railway operation, it is important to have a common way of understanding railway capacity, although railway capacity can be understood and analyzed in different ways during the planning phases. By having a common definition of railway capacity it is easier to communicate capacity between organizations and planning Phases.(14)

The UIC 406 capacity leaflet describes a method to measure railway capacity consumption for a given infrastructure—the UIC 406 capacity method. This method defines railway capacity as “the total number of possible paths in a defined time window, considering the actual path mix or known developments respectively…” (UIC 2004). To measure the railway capacity consumption, timetable graphs can be used whereby the given infrastructure and the type of rolling stock are implicitly included as they determine the size of the blocking stairs. The capacity consumption is measured by compressing the timetable graphs so that the buffer times are equal to zero, figure 11. This considers the minimum headway times, which depend on the signaling system and train characteristics (Sewcyk, Radtke & Wilfinger 2007).(14)

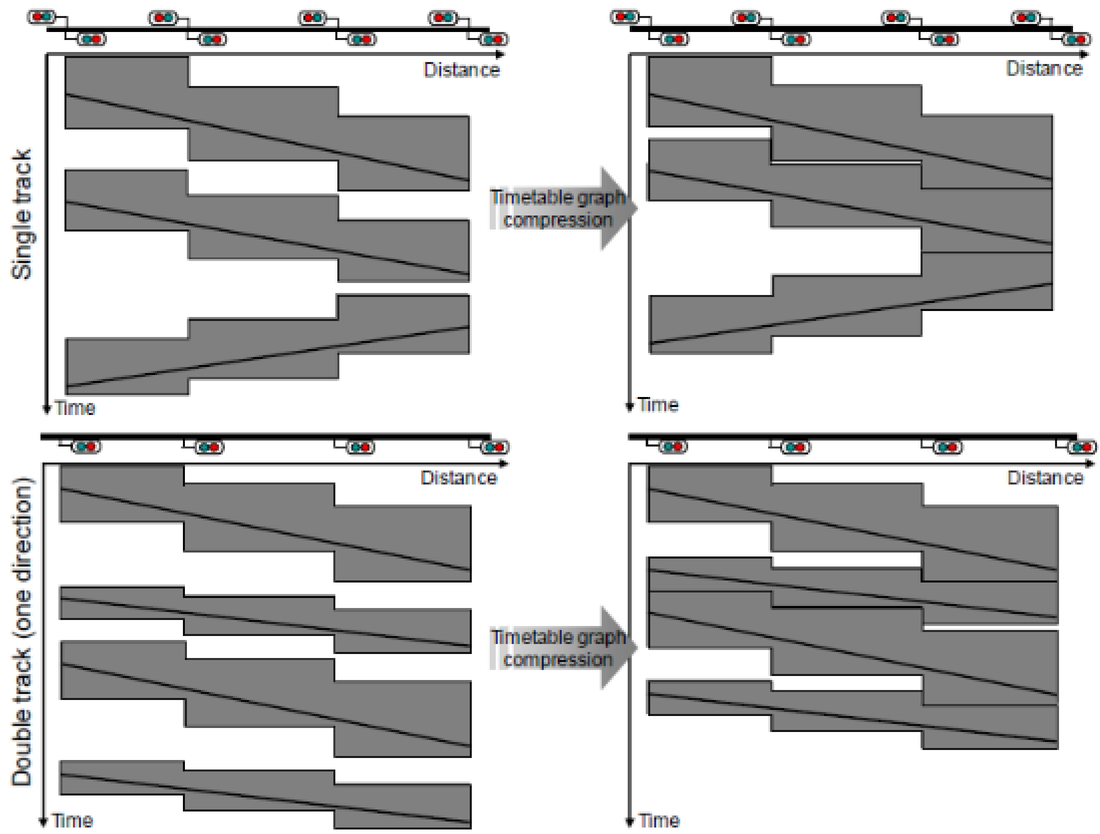


Figure 11: Compression of timetable graphs according to the UIC406 capacity method. Partly based on (Landex et al. 2007).

It is difficult, or even impossible, to compress the timetable for an entire complex railway network as train routes are interwoven. Therefore, it is necessary to divide the network into smaller line sections that can be handled by the UIC 406 capacity method. Railway lines are, according to (UIC 2004), divided into smaller line sections at junctions, overtaking stations, line end stations, transitions between double track and single track (or any other number of tracks) and at crossing stations.(14)

The total capacity consumption (k) can also be calculated in a more analytical way by summing the infrastructure occupation time (t_A), the buffer time (t_B), the time supplement for single track lines (t_C) and maintenance (t_D) (UIC 2004):(14)

Formula1: $k = t_A + t_B + t_C + t_D$

The capacity consumption in per cent (K) can be worked out based on the total capacity consumption measured in time (k) and the chosen time window (t_U) (UIC 2004):

Formula 2: $K = k * 100\%/t_U$

The expressions in formula1 and formula 2 can be expressed differently to calculate the capacity consumption in one step (Landex et al. 2007).

Formula 3: $K = (t_A + t_B + t_C + t_D) * 100\%/t_U$

The infrastructure occupation time (t_A) and the time window (t_U) are the most important factors in formula 3. This is because the infrastructure occupation time makes up most of the capacity consumption of the time window examined (t_U). The buffer time (t_B) is normally set equal to zero but can be set to a different value to improve the quality of the operation by ensuring fewer consecutive delays. It could be argued that the buffer time is a kind of quality factor.(14)

The time supplement for single track operation (t_C) can be added at the crossing stations the same way to improve the quality of the operation by reducing the risk of consecutive delays. Alternatively, the time supplement for single track operation can be used in the completely analytically examination of the capacity consumption. This is done by considering the running time from the entrance of the station to the release of the train route before the train in the opposite direction can depart from the platform together with the extra time it might take if the crossing station cannot handle parallel movements. (14)

The time for setting up and clearing the train routes might be reduced by changing to a (more modern) signaling system that works faster. The signal realizing time might be reduced by changing to driverless operation, as the realization and the reaction time of the driver can then be eliminated, or at least reduced. However, these topics represent only a small part of the block occupation time. Most of the block occupation time is actually used for the train to approach and pass the block section and for releasing the train route. Reducing the length of the block sections reduces the time it takes the trains to pass through the block sections, which will gain capacity. Alternatively, the block sections can be passed faster by running faster. However, by running faster the braking distance, and thereby the approach time increases, which results in a limit of the capacity gain of increasing the speed.(14)

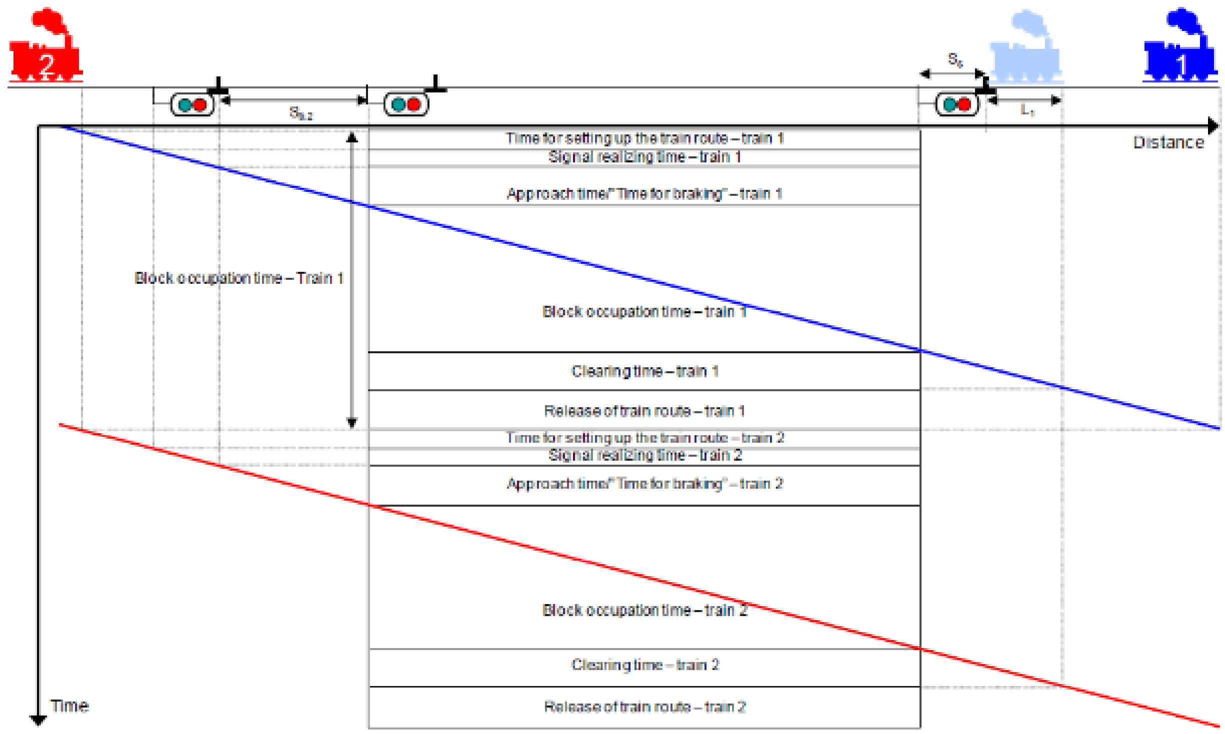


Figure 12: Elements of the block occupation time. Based on (Kaas 1998b, Landex, Kaas & Hansen 2006, Pachl 2002, Pachl 2008, UIC 2004).

As capacity consumption on railway lines depends on both the infrastructure and the timetable, the capacity calculation according to the UIC 406 method is based on an actual timetable. The timetable is worked out for the entire network and not only the line or line section, which is of interest according to the capacity analysis. This means that the timetable in the analysis area depends on the infrastructure and timetable outside the analysis area (Hansen, Landex & Kaas 2006, Landex, Kaas & Hansen2006, RMCon 2007).(14)

There are many differences between double and single track railway lines, also regarding the capacity. Double track railway lines can generally operate significantly more trains (up to about 30 trains per hour in each direction) than a single track railway line (up to about 6 trains per hour in each direction). This is possible because the trains hardly ever have to share the same infrastructure for both directions; accordingly, the timetable can be planned for each direction virtually independently.(14)

For single track railway lines, the crossing stations and the running time between the crossing stations (including dwell time, set-up and release of routes) in cases of no bundling of the trains is equal to half the possible frequency on the line section. The location of the crossing stations is important because the running time between the stations must be at maximum the half of the frequency. If just one crossing station is located too far away (measured in running time and possible dwelling time), it is not possible to maintain the scheduled frequency.(14)

According to the UIC 406 capacity method, railway lines must be divided into smaller line sections. The railway lines should be divided at each junction, when the number of tracks changes (e.g. from double track to single track) and at each crossing station. Furthermore, the railway lines must be divided into line sections where the number of trains or the train order changes (e.g., line end stations where trains turn around) and at stations where trains overtake. Figure 13 shows a schematic track layout and where the railway line must be divided into line sections.(14)

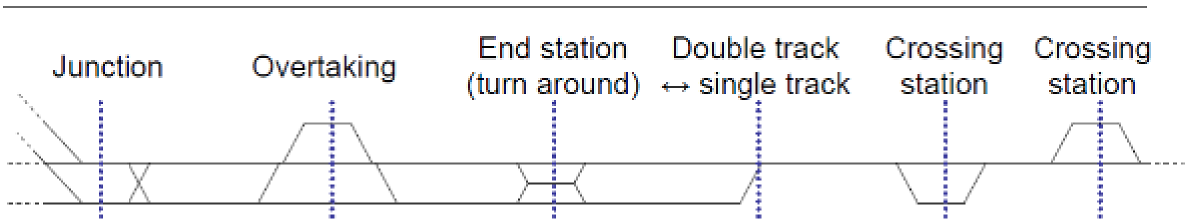


Figure 13: Dividing a railway line into line sections (Landex et al. 2006a, Landex et al. 2006b).

For single track railway lines, special attention must be paid to the crossing stations. Some crossing Stations have parallel movement facilities, while other crossing stations can handle only one approaching train at a time.(14)

To have parallel movement facilities, it is necessary to create a sufficient safety distance (SS) behind the exit signal. This can be achieved in two ways. Either by means of a dead-end track (the left side of the crossing station in figure 14) or by placing the exit signal at the necessary safety distance (SS) from the fouling point (the right side of the crossing station in figure 14) (Kaas 1998b, Landex, Kaas & Hansen 2006).(14)

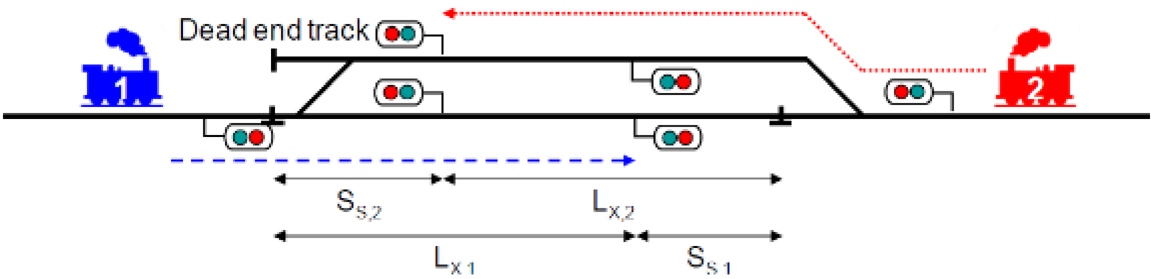


Figure 14: Station with parallel movement facility. Based on (Landex et al. 2007).

If a crossing station is unable to handle parallel movement, one of the trains must stop at the crossing station for a longer time while the other train enters the station, figure 15.

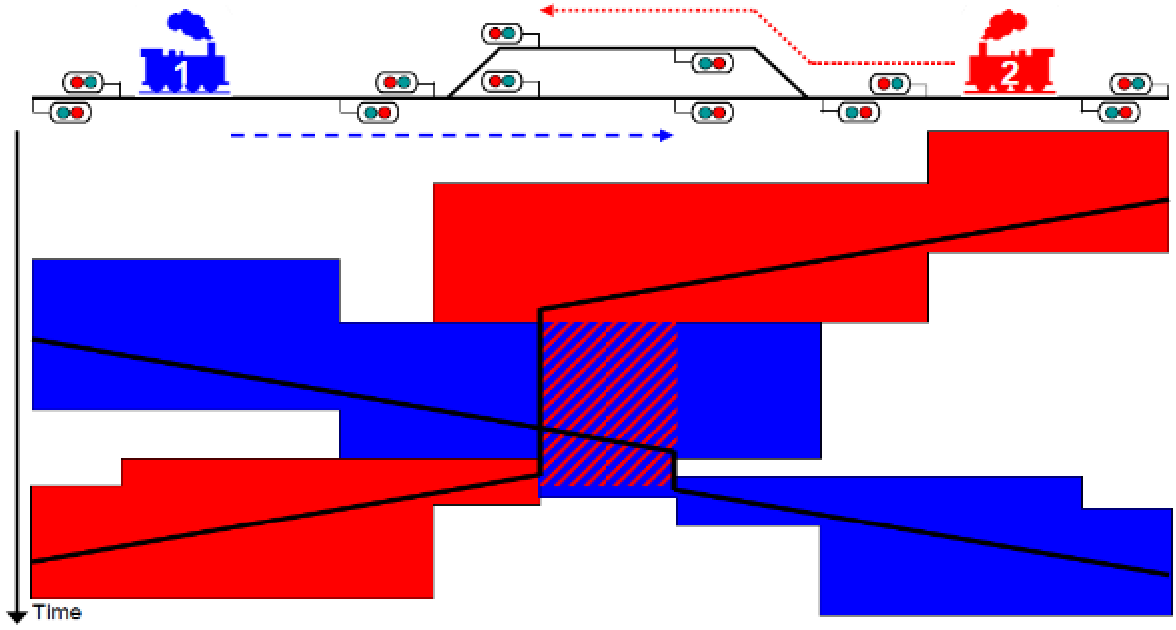


Figure 15: Crossing station without parallel movement facility (Landex 2009).

The dwell time of train 2 is considerably longer than that of train 1 because the route of train 2 has to be released before train 1 may enter the crossing station. After train 1 has entered the crossing station its route has to be released to set up the departure route of train 2 from the station.(14)

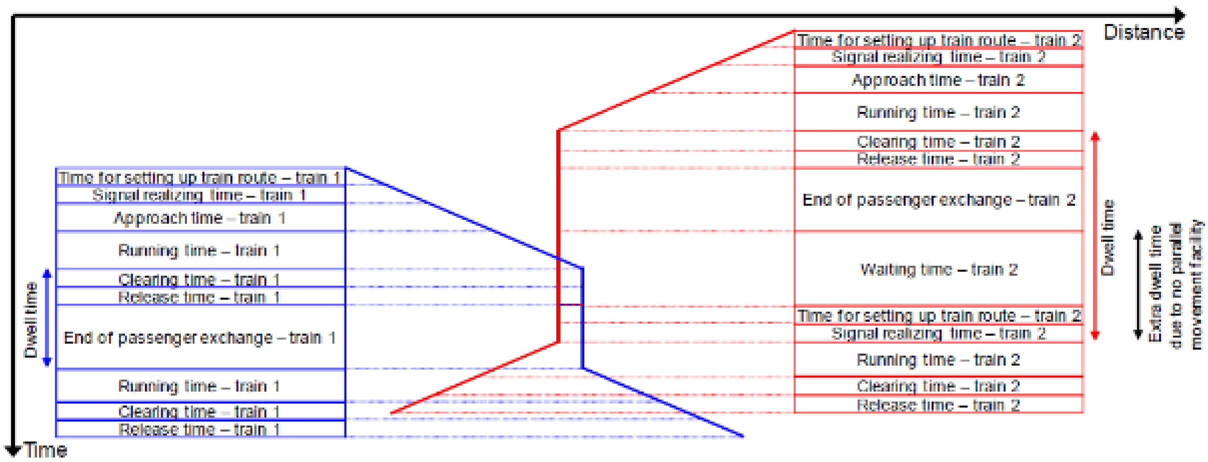


Figure 16: Detailed block occupation time for platform tracks of a crossing station. Based on (Landex 2009).

It is not only at crossing stations that it can be necessary to extend the line section so that the area further ahead is examined. At junctions it is necessary to include the entire junction and the conflicting train movements to estimate the capacity.
At the junction shown in figure 17, train route 2 may limit the capacity for two other trains running immediately after each other on train route 1. The reason for the “lost” capacity is that the order of the trains according to the UIC 406 leaflet should be

maintained (UIC 2004). This is because the train order is a result of a thorough planning process where market issues, network effects, timetable stability etc. have been taken into account, and a change in the train order would ignore this planning process.(14)

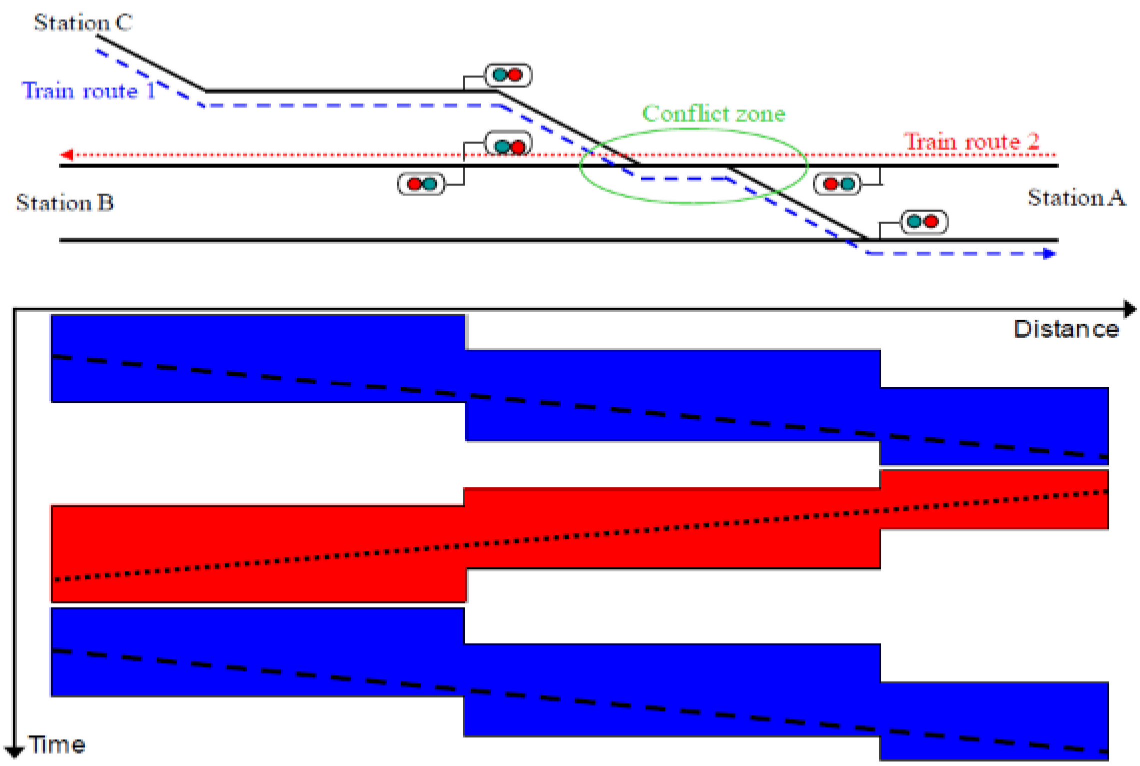


Figure 17: Capacity reduced for two trains running immediately after each other at a junction (only signals in use included). Based on (Landex 2009).

Capacity is a measure of the ability to move a specific amount of traffic over a defined rail line with a given set of resources under a specific service plan.(15)

2.9 ASSESSMENT OF RAILWAY CAPACITY

Theoretical Capacity: It is the number of trains that could run over a route, during a specific time interval, in a strictly perfect, mathematically generated environment, with the trains running permanently and ideally at minimum headway (i.e. temporal interval between two consecutive trains). It is an upper limit for line capacity. Frequently, it assumes that traffic is homogeneous, that all trains are identical, and that trains are evenly spaced throughout the day with no disruptions. (16)
Practical capacity: it is the practical limit of "representative" traffic volume that can be moved on a line at a reasonable level of reliability. Thus, practical capacity is calculated under more realistic assumptions, which are related to the level of expected operating quality and system reliability, as shown in figure 18. It is the capacity that can permanently be provided under the normal operating conditions. It is usually

around 60%-75% of the theoretical capacity, which has already been concluded by kraft (1982).(16)

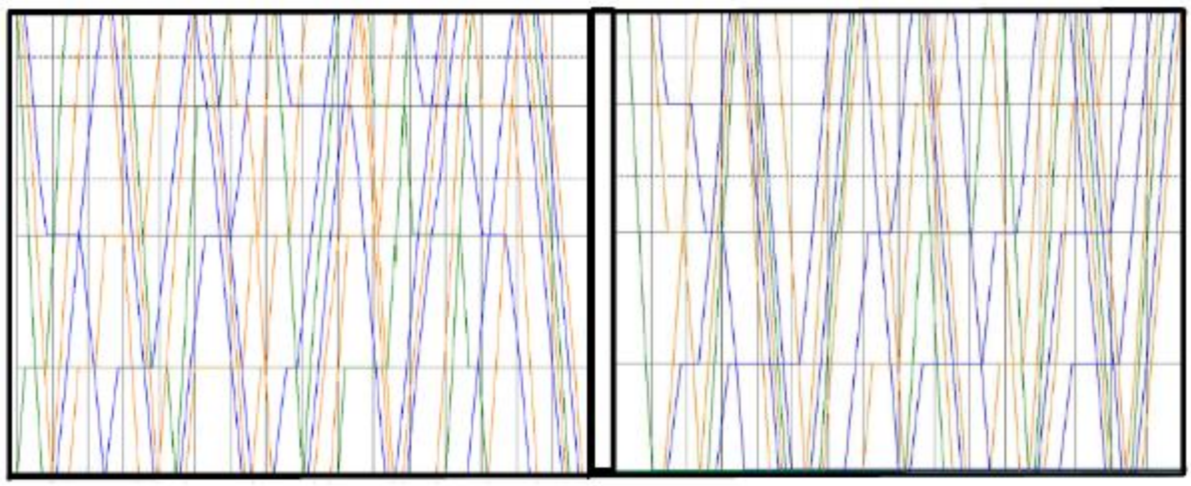


Figure 18

Block and signaling system: The signals help extends the train driver's visibility, so it allows greater speeds. The role of signaling is to keep trains at a safe distance. In a moving block signaling system, which is a modern technology, the position of each train is known continuously, thus permitting better regulation of the relative distances.(16)

Single/double tracks: This has a major impact on capacity. It is not as simple as multiplying the number of tracks: two tracks usually have around four times more capacity than a single track; however, a four-track line rarely increases capacity by more than 50% over a double line (Kittelson and Associates, 2003). Furthermore, adding a second track may not eliminate the problem because the station is the real bottleneck.(16)

Track structure and speed limits: The condition of the rails, ties, and ballast dictate the weight and type of equipment that can be used on the line, as well as the speeds allowed on the line. They have an important influence on the capacity.(16)

Numerous approaches have been developed to evaluate railway capacity. The most relevant methods can be classified in three levels: Analytical Methods, Optimization Methods, and Simulation Methods.(16)

Analytical Methods: These are very simple models aimed at determining a preliminary solution. These methods can also be used for reference or comparison. They are designed to model the railway environment by means of mathematical formulae or algebraic expressions.(16)

The International Union of Railways, more generally known as the UIC (from its French name, Union International des Chemins de fer), proposed the UIC method (UIC, 1983); it calculates capacity in line sections to identify bottlenecks.(16)

Optimization Methods: Optimization methods for evaluating railway capacity are based on obtaining optimal saturated timetables. These optimal timetables are usually obtained by using mathematical programming techniques (Mixed Integer Linear Programming formulations and Enumerative algorithms). (16)

Simulation Methods: A simulation is the imitation of an operation of a real-world process or system over time. It is the representation of dynamic behavior of a system by moving it from state to state in accordance with well-defined rules.(16)

OpenTrack (OpenTrack Railway Technology) is a simulation tool to answer questions about railway operations. It calculates train movements under the constraints of the signaling system and timetable. It also handles simulation where random generators produce different initial delays and station delays.(16)

The new policy of the European Union is to encourage open access to railway networks. This process has already begun in the Spanish Administration of Railway Infrastructure, ADIF, which is interested in using advanced computer tools to improve railway management. In collaboration with ADIF, the authors have developed a tool called MOM (acronym of the Spanish name: Modulo Optimizador de Mallas) that embeds analytical and optimization approaches in this context.(16)

The capacity of a double-track line in a fixed time period depends on the Headway Time between consecutive trains. This Headway Time is the maximum of all Headway Times between consecutive virtual signals of the line. In each line section, capacity is:(16)

$$\text{Capacity} = \frac{Time\ period}{Headway\ Time} \Rightarrow$$

$$\text{Capacity} = \frac{Time\ period}{F\left(\frac{Distance}{Speed}\right)+F'\left(\frac{Speed}{Deceleration}\right)+F''\left(\frac{Length}{Speed}\right)+OT}$$

The following formula shows that capacity is strongly dependent on the train speed: It is directly proportional to speed due to the Travel and Release Times, but it is indirectly proportional to speed due to the Braking Time. When speed is constant, the following formula can be simplified as:(16)

$$\text{Capacity} = \frac{Time\ Period}{\frac{Distance}{Speed}+\frac{Speed}{Deceleration}+\frac{Lenght}{Speed}+OT}$$

The proposed computer-based tool is used to analyze the influence of several parameters in ERTMS lines. All the data and figures have been automatically obtained by the MOM system.(16)

Figures 19 and 20 shows the Headway Times of a railway line whose line sections have constant lengths. Specifically, in Figure 19, the line sections are 6000 meters long, which mean that the distance between consecutive virtual signals is 6000 meters. The train speed increases from 200 Km/h up to 500 Km/h. (16)

Figure 19 shows the dependency of capacity on train speed. As can be observed, when the train is slow, the Travel Time influences capacity more than the Braking Time. However, when the train is fast, capacity depends mainly on the Braking Time. The Operating Time (OT) and the Release Time (Length=Speed) are much smaller than the Travel and Braking Times.(16)

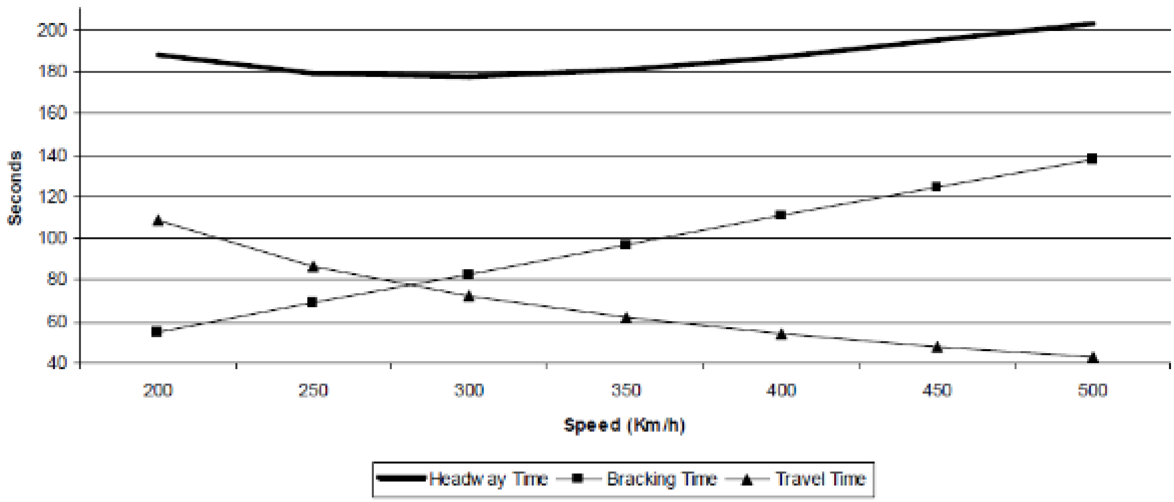


Figure 19

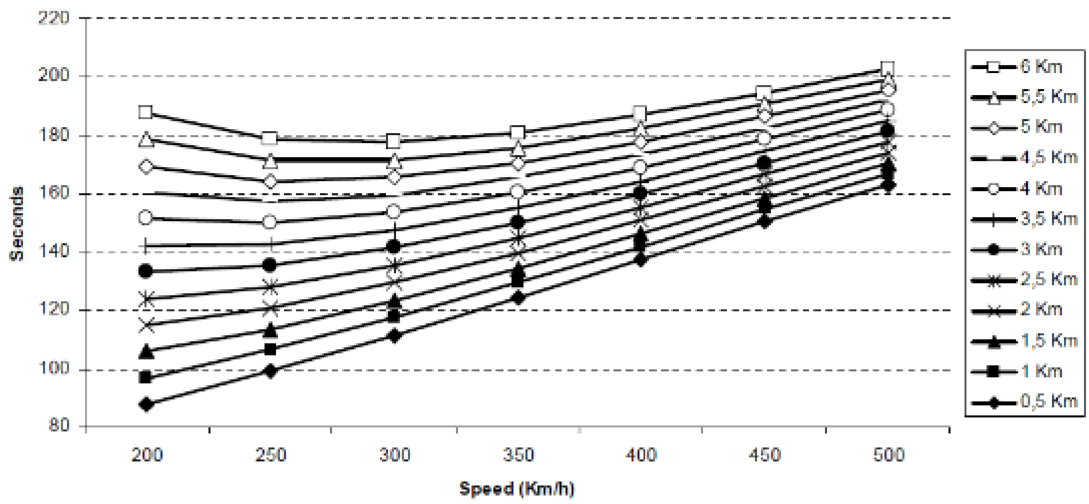


Figure 20

In Figure 20, we analyze the influence of train speed on capacity with different line section lengths. For short line sections, when the train speed increases, the Headway Time also increases. However, for large line sections, the minimum Headway Time is obtained with a medium train speed. This is due to the fact that the Braking Time and the Travel Time are balanced. (Figure19). As mentioned formula indicates, the minimum Headway Time gives the maximum capacity. (16)

Figures 21 and 22are showing the influence of another important factor the distance between consecutive virtual signals. At a given speed, as the distance gets bigger, the Headway Time increases. Furthermore, the distance has a large influence on the Headway Time when the speed is slow. Figure 21 shows that when the speed is 200 Km/h, the Headway Time grows faster than when the speed is 500 Km/h. This is due to the fact that the Travel Time depends on the distance between consecutive virtual signals. As Figure 22a shows, when the speed is slow, the Travel Time tends to be bigger than Braking Time. However, when the speed is fast, the Travel Time tends to be smaller than the Braking Time, showing that the influence of Travel Time is less significant (Figure 22b). This is why the lines cross in Figure 21. (16)

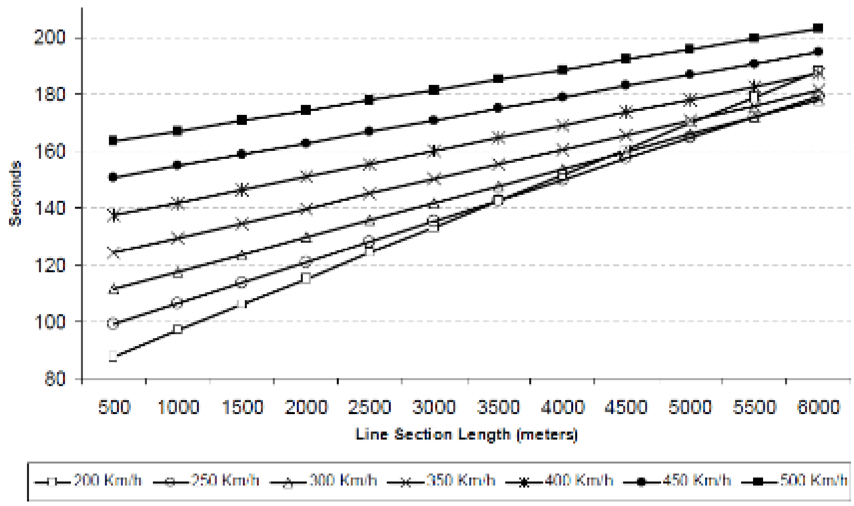
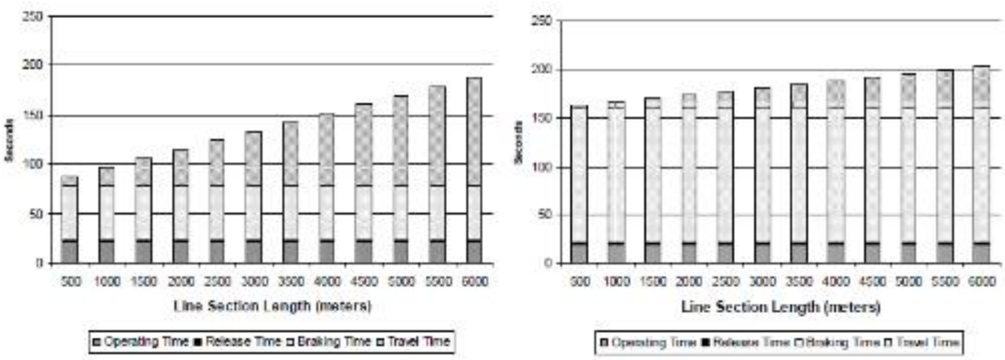


Figure 21



(a) Speed = 200 Km/h.
(b) Speed = 500 Km/h.

Figure 22

2.10 TRAINS WITH CONSTANT ACCELERATION

Figure 23 shows the maximum capacities according to the Headway Time of each section. The line capacity is limited by the sections with the greatest Headway Time; which are the sections with the maximum speed. Thus, in this case, the maximum line capacity is 16 trains.

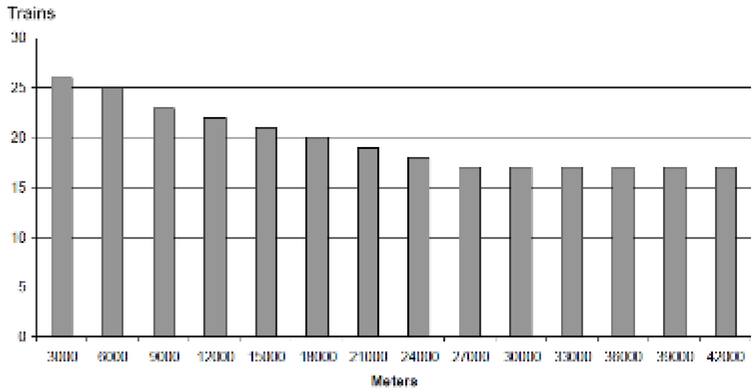
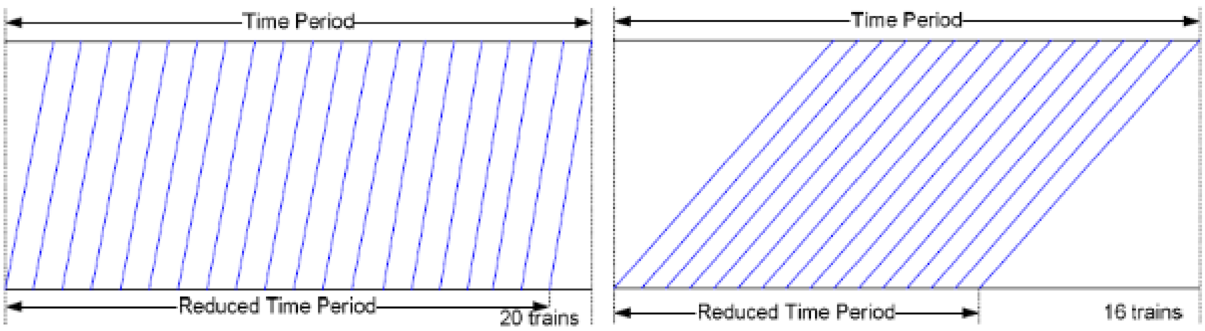


Figure 23

We can conclude that the Braking Time is a prominent time in the Headway Time. Therefore, the ability to decelerate is an important factor in increasing capacity. Likewise:

Section distances between signals inversely affect capacity, mainly at lower train speeds (Figure 21). (16)

Train speed has a complex influence on Headway Time in large sections (Figure 20). In shorter sections (≈< 4 Km), the train speed directly affects the Headway Time. As the Headway Time increases, trains should be more separated and capacity should decrease. However, with a discontinuous time period (Figure 24b), if the speed increases, more trains can be scheduled in a given time period subsequently capacity increases (Figure 24). Broadly speaking, in a time period, we can put n trains, such that:



(a) Faster trains. More trains in the *time period*, but more separated.

(b) Slower trains. Fewer trains in the *time period*, but closer together.

Figure 24

n = (TimePeriod - JourneyTime)=Headway Time. Therefore, assuming an ideal case of trains running at regular speed between two locations that are separated by 300 Km, Figure 25 shows the maximum capacity in a time period of 8 hours, depending on the distance between signals and train speed.(16)

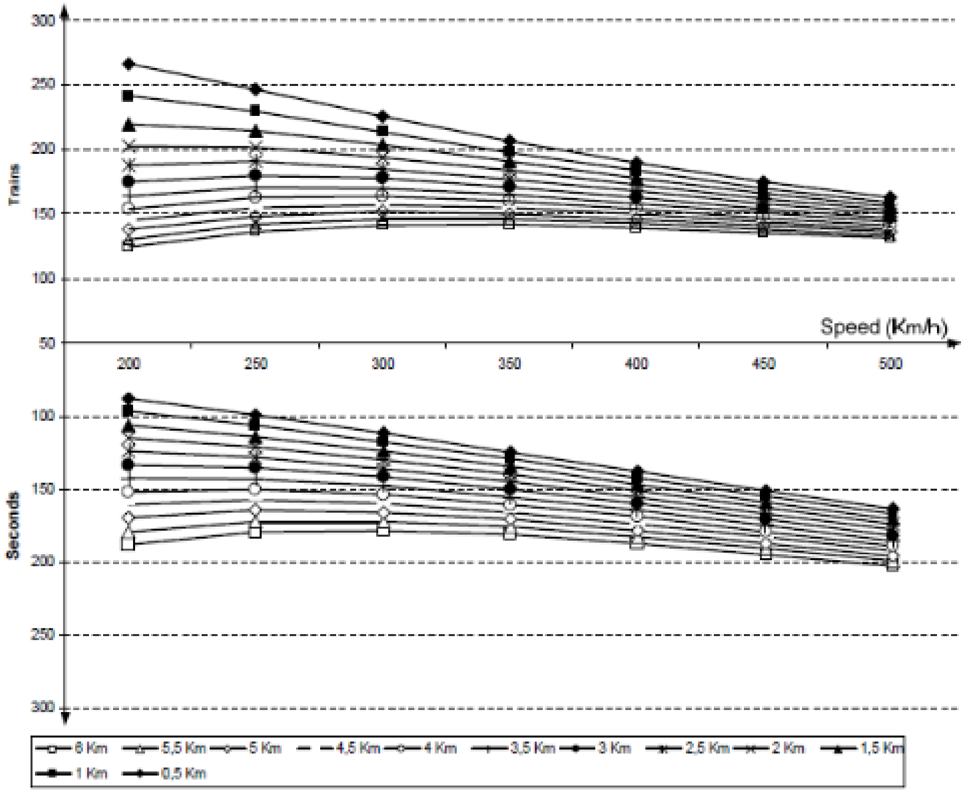


Figure 25

Factors like train length or Operating Time do not affect the capacity significantly. However, train length could be important in very large trains.

In the vertical right axis of Figure 26, it can be observed that the maximum speed limit (which in ERTMS level 2 is 500 Km/h) is never reached. The most crucial time along the line for calculating the Headway Time is the Braking Time, with the exception of the section where a commercial stop is carried out. This section has the greatest Headway Time because of the Travel and Release Times. Therefore, this section has the smallest capacity, which is 16 trains (see Figure 27).(16)

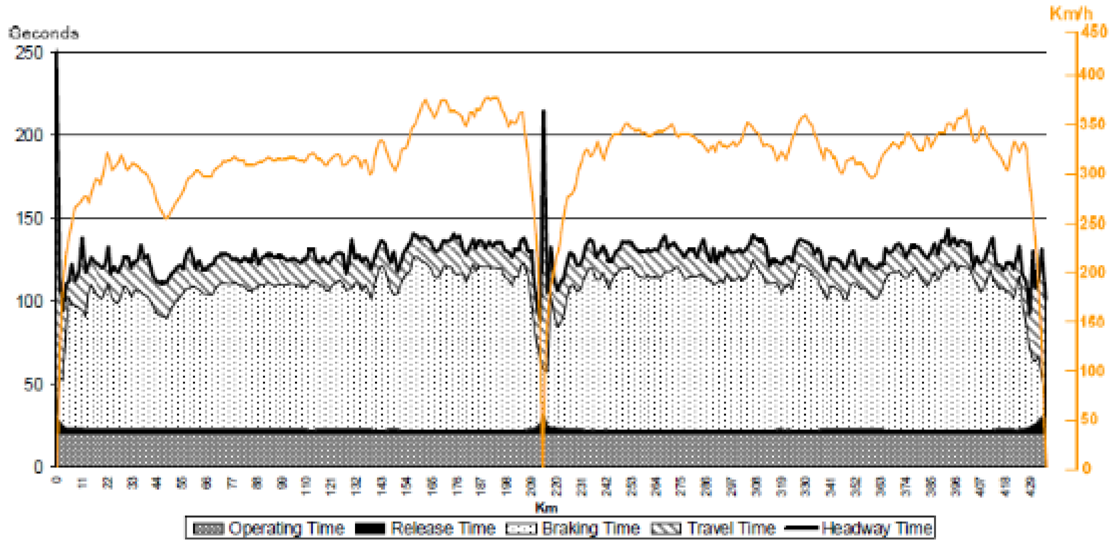


Figure 26

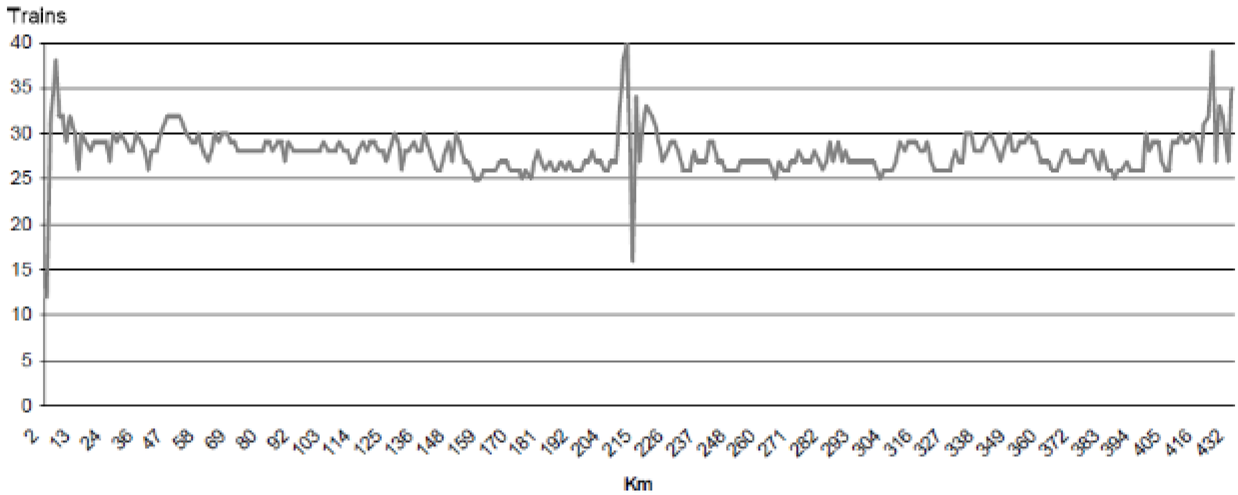
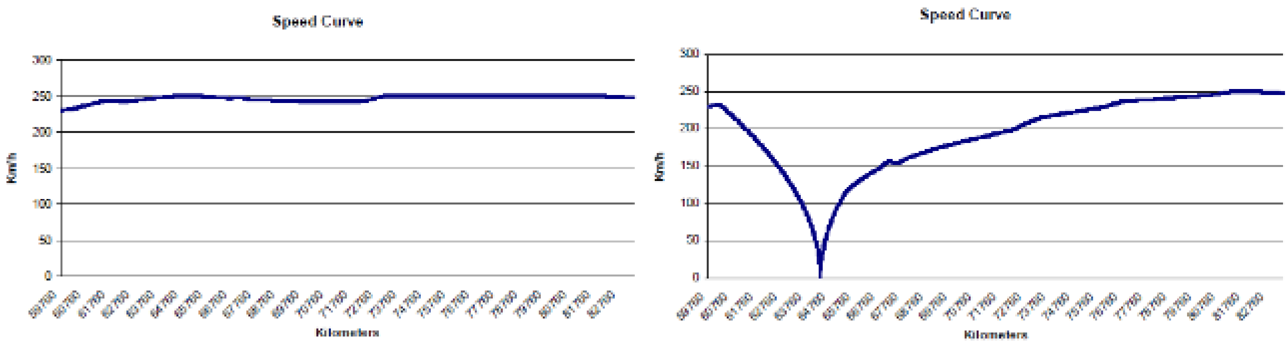


Figure 27

We show how the line capacity decreases when a new commercial stop is introduced into a line with ERTMS. This is mainly due to the changes in speed.
Figure 28 shows two different train speed curves for one railway line. Figure 28a shows the speed curve when the train does not stop, and Figure 28b shows the speed curve when the train performs a stop. This last figure shows how the train decelerates and accelerates. (16)



(a) Speed curve without stop. (b) Speed curve with stop.

Figure 28

Figures 29 and 30 are showing the Headway Time difference between a train without a stop or with a stop. When the train decelerates and accelerates, the Headway Time of the affected line sections increases or decreases. Specifically, in the line section where the train stops (in this example, the third section), the Headway Time increases a lot (Figure 30). Therefore, the capacity of this line section decreases. Figure 31 shows how the capacity of the third line section decreases from 29 trains (Figure 31a) to 14 trains (Figure 31b). (16)

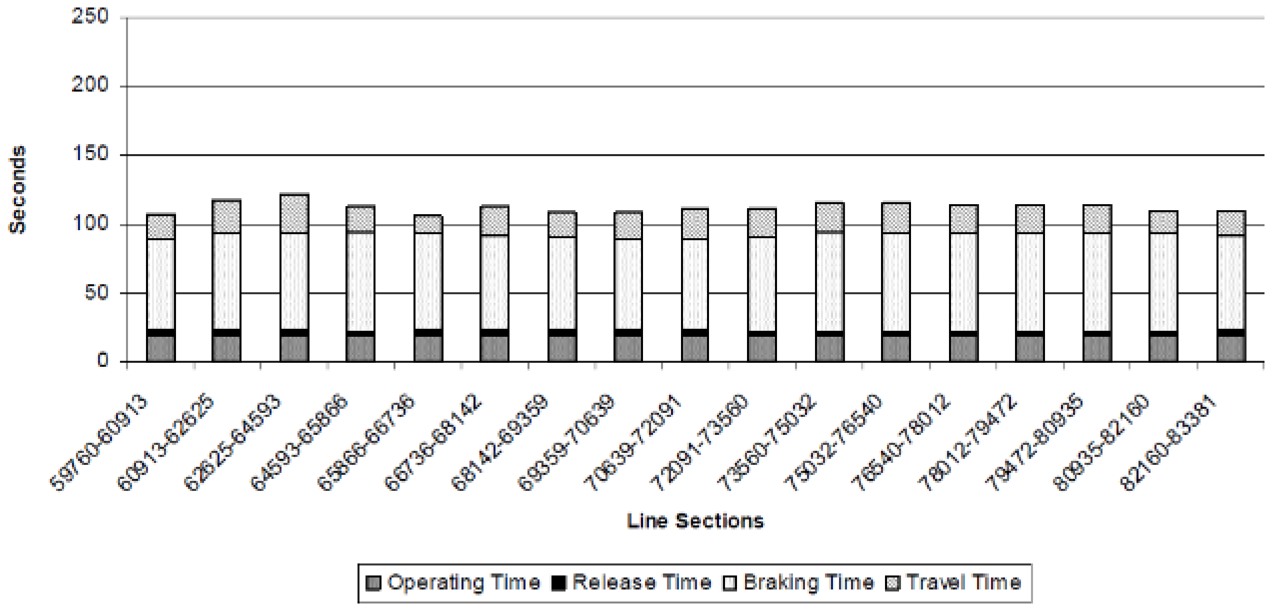


Figure 29

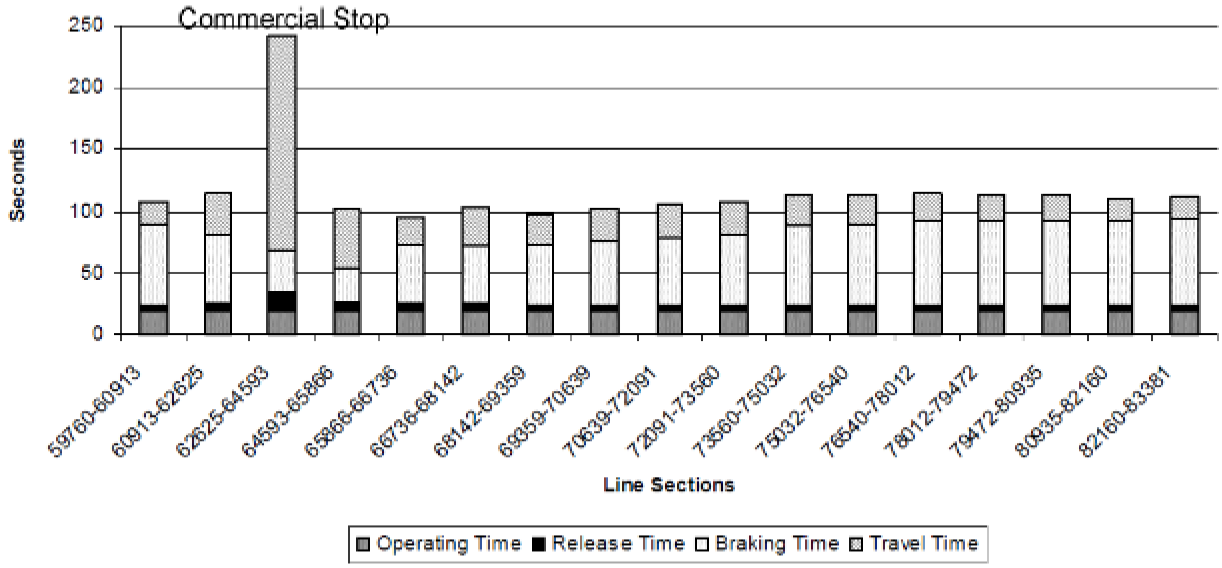
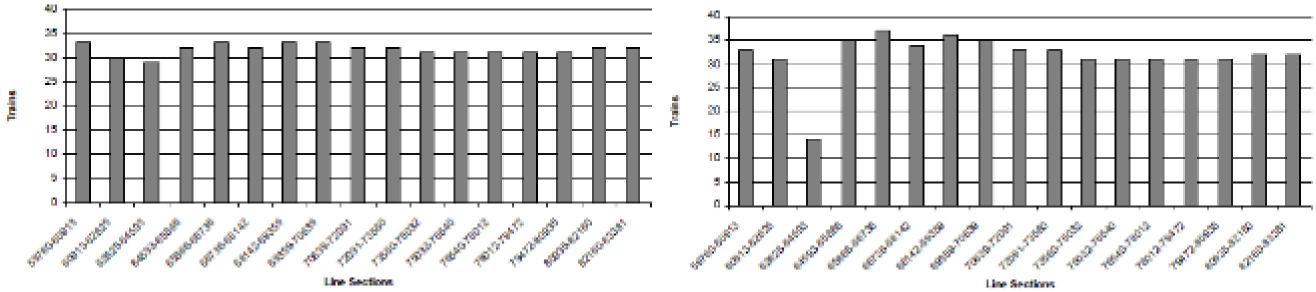


Figure 30



(a) Maximum capacity without stop.

(b) Maximum capacity with stop.

Figure 31

2.11 CAPACITY OF NODES

The capacity of a node must be considered as the capability of the node itself to receive trains on the tracks in the reference time without delays at traffic signals.

It depends on the on the structure of the timetable or rather by the frequency of arrivals, which regulate the minimum lines headway, the topology of the system which determines the incompatibility and the interlocking system features.(17)

The second step is the definition of the requested type of railway capacity that the user wants to obtain. Four types of railway capacity have been taken into account. The theoretical capacity is defined as the number of trains that could run on a certain line section in a defined reference time in case of unperturbed operation, corresponding to the headway for all classes of trains and operational programmers. The commercial capacity represents the portion of the actual capacity calculated taking into account the actual operation of the railway and its interaction with the network. The Used capacity is the actual capacity committed by a particular rail system under certain operating conditions that is absorbed by a timetable. The residual capacity is the portion of the capacity still available to meet new demands in a timetable and/or under perturbed operation.

At the third step the user should list the available input data and select the relative fields into the three main categories defined as: infrastructure parameters, network effects and operational effects. This categorization is due to the fact that railway capacity is not static. It is extremely dependent on how it is used. The physical and dynamic variability of train characteristics makes capacity dependent on the particular mix of trains and the order in which they run on the line. Furthermore, it varies with changes in infrastructure and operating conditions. Also the above three categories defined give a first element on the way different factors that affect on railway capacity are linked.

The steps above complete the user's input data procedure. The system takes into account these data, elaborates the different combination of the above and generates a first list of available methods of calculation of railway capacity. Available methods are those that have been analyzed by the authors during the present research and comply with user's selection of input data. The different techniques and methodologies for calculating the capacity can be divided into three main categories according to the used methodology, the compiled data and the level of detail. They are:

Synthetic: they use deterministic expressions, i.e. the variables contained in these cannot change its state and assume fixed values during the reference time, from the mathematical point of view they are equations were the unknown quantities are mutually independent, they are also called static.

Analytical: they use probabilistic expressions, from the mathematical point of view they are equations were the unknown quantities are mutually dependent, they are also called dynamic.

Analogical: can be further divided into asynchronous methods (this covers methods which provide the optimization of one or more variables) and synchronous methods (traffic simulation), for instance the optimization methods are based on procedures looking for delays minimization in the mixed speed traffic, as well as the simulation methods represent the evolution of advanced research and are often used to validate the results other methods.(17)

2.12 EFFECTIVE PARAMETERS ON CAPACITY

Usually increment of number of tracks in all or part of an overloaded line seems the simplest and clear solution. However, investments into infrastructure are very large and expansion of infrastructure in populous territories may be impossible. Therefore, all means enabling limitation or avoidance of infrastructure development or reconstruction have to be discussed. (13)

The main parameter influencing railway line capacity is difference in train speeds. Increasing the difference between the highest and the lowest train speed, feasible line capacity decreases. Reduction of the difference between train speeds enables increment of railway line capacity without changing infrastructure. (13)

A research estimating variables that determine commercial speed of trains and their importance is presented in the article. The commercial speed of trains depends on rolling stock traction and characteristics of breaking system, stoppage duration and some traffic control conditions. To decrease the difference between the trains speeds the speed of the slowest trains has to be increased but the speed of the high speed trains must not be decreased. The freight trains and the passenger trains that stop in the intermediate stations very often are the slowest ones in the mixed traffic railway lines. Influence of different variables is evaluated using sensitivity analysis thus estimating potential increase in capacity.(13)

It is not difficult to estimate the capacity in a line where the train speeds and stopping characteristics are identical. Train routs in the diagram are homogeneous. In such case the capacity is inversely proportional to minimal interval.(13)

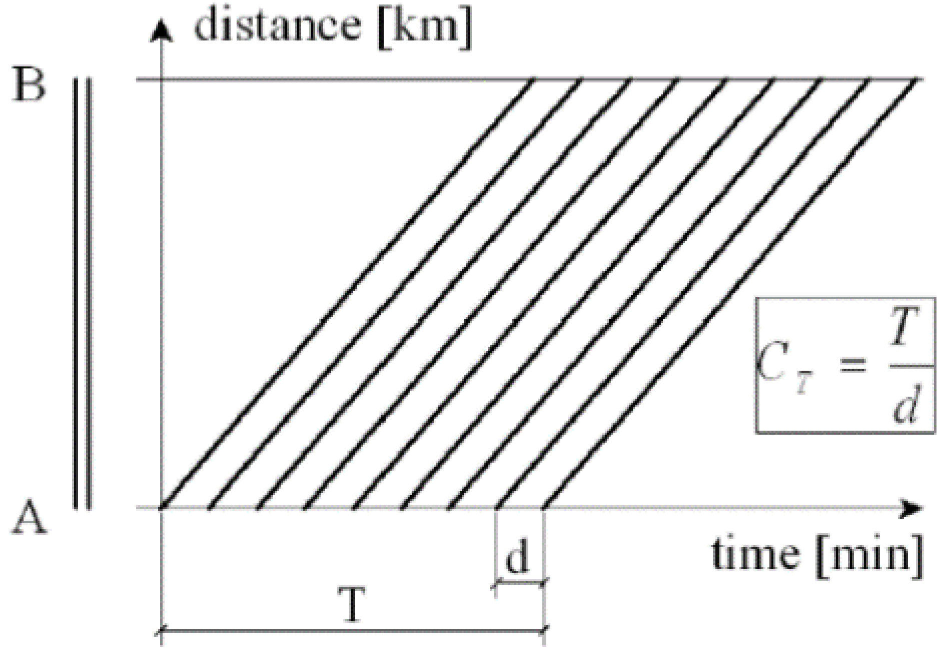


Figure 32: Line capacity in homogeneous traffic

Mixed traffic with trains of different categories, having different stopping characteristics is the most common in many lines. As speeds are not the same and times in the train schedules are not homogenous the line capacity is influenced by two more factors (Dessouky et al. 2010; Harrod 2007): distance between contiguous stations where faster train can overtake the slower ones; train driving order, i.e. order of routs in a district.(13)

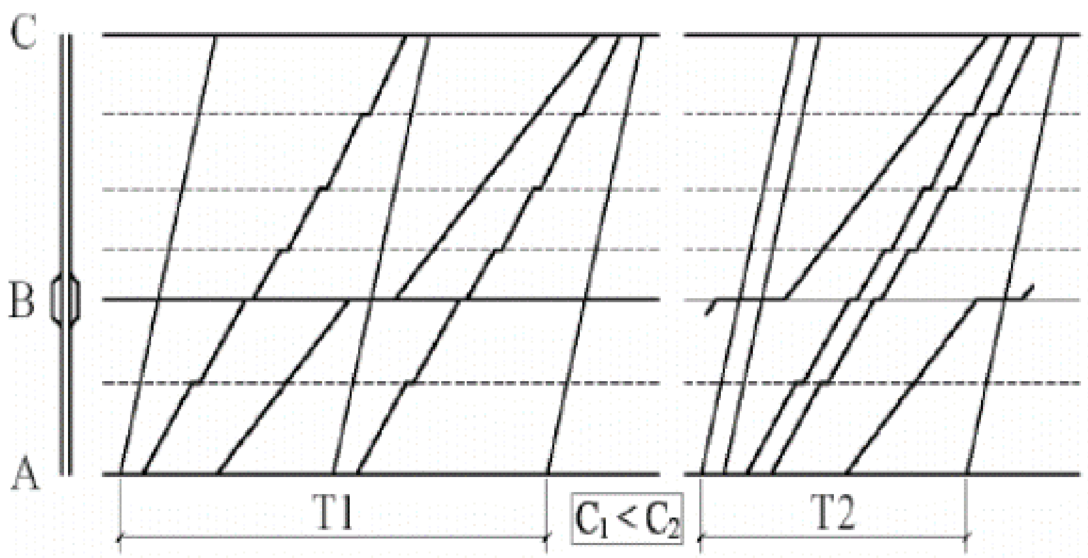


Figure 33: line capacity in the mixed traffic

Railroad line capacity depends on many factors:(18)

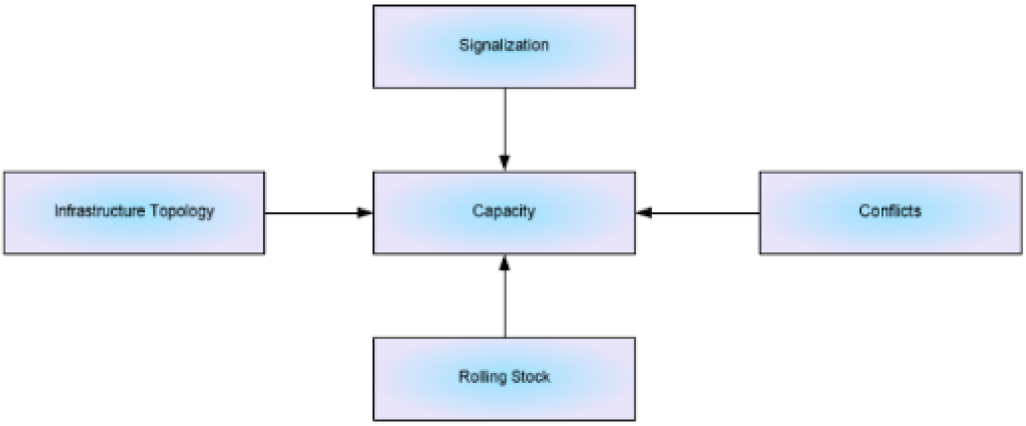


Figure 34: capacity dependences

Rolling stock has influence on the speed, acceleration and deceleration time.(18)

Infrastructure topology influences on Railway capacity. Leveling-off of rise and fall, construction of the second way for the single way section between the stations, railway extension allow to increase the capacity of stations and sections between them.(18)

Signalization equipment Semi- automatic signalization system allows only one train to be in a line side and when there is a long distance between station, the one-line block can cross only be only 2–3- trains in 1 hour. For example, the capacity of the line with a semi-automatic system may be 2–2.5 times smaller than lines with automatic.(18)

Conflicts may compress traffic trains graph to the point where the average speed drops and correspondingly it reduces line capacity.(18)

Chapter 3
Case Study and Methodology

3.1 WESTERN LINE

The total Ghana rail network extends for 939 kilometers of routes (1,200 km of tracks, including double-track sections), all located in the southern regions; it is made up of the Western, Central and Eastern-Lines. The country's railway operates through various cities, major and small towns.

The Western Line links Takoradi and Kumasi, serving Tarkwa, Huni Valley, Dunkwa and Obuasi.

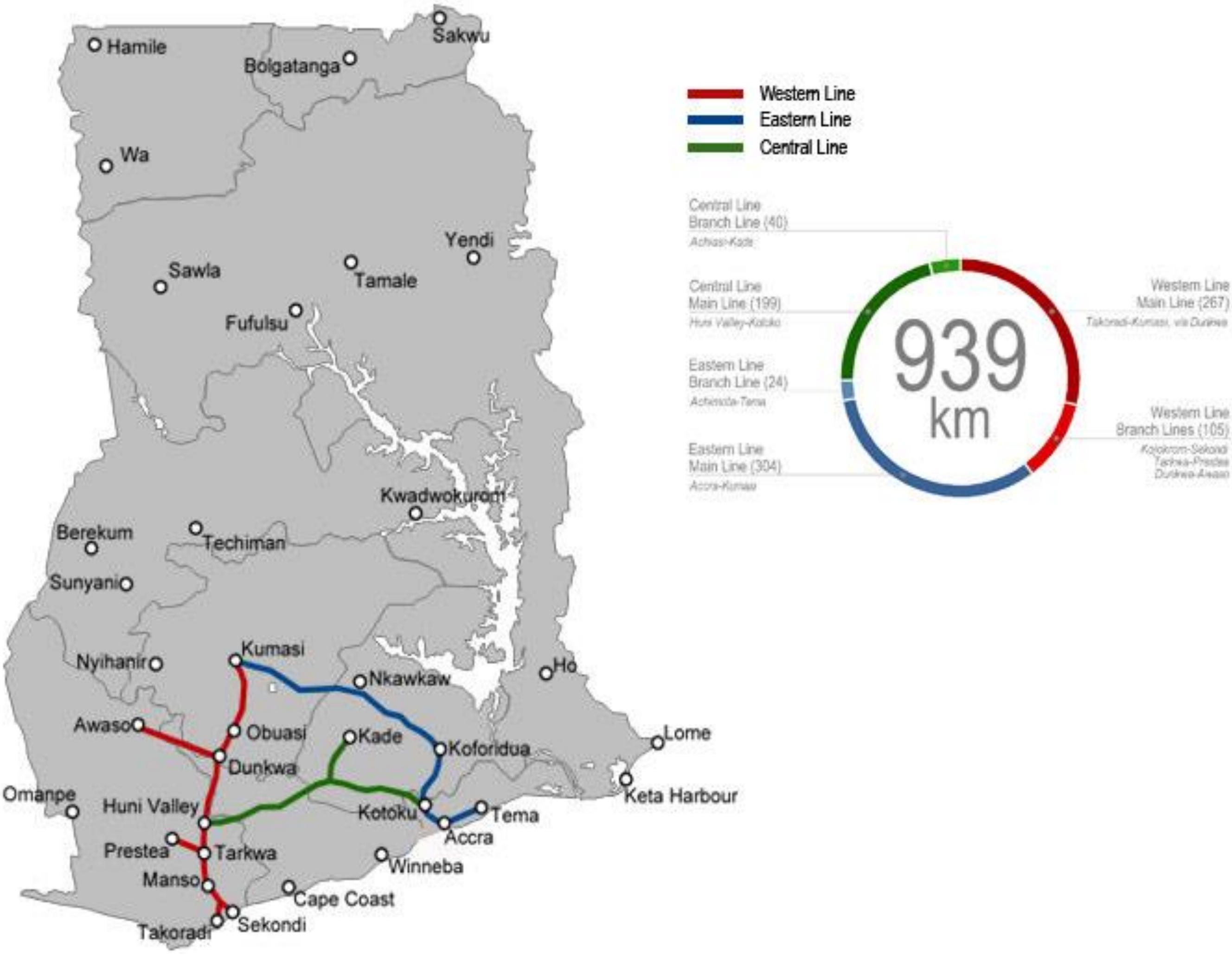


Figure 35: Ghana Existing Railway Network

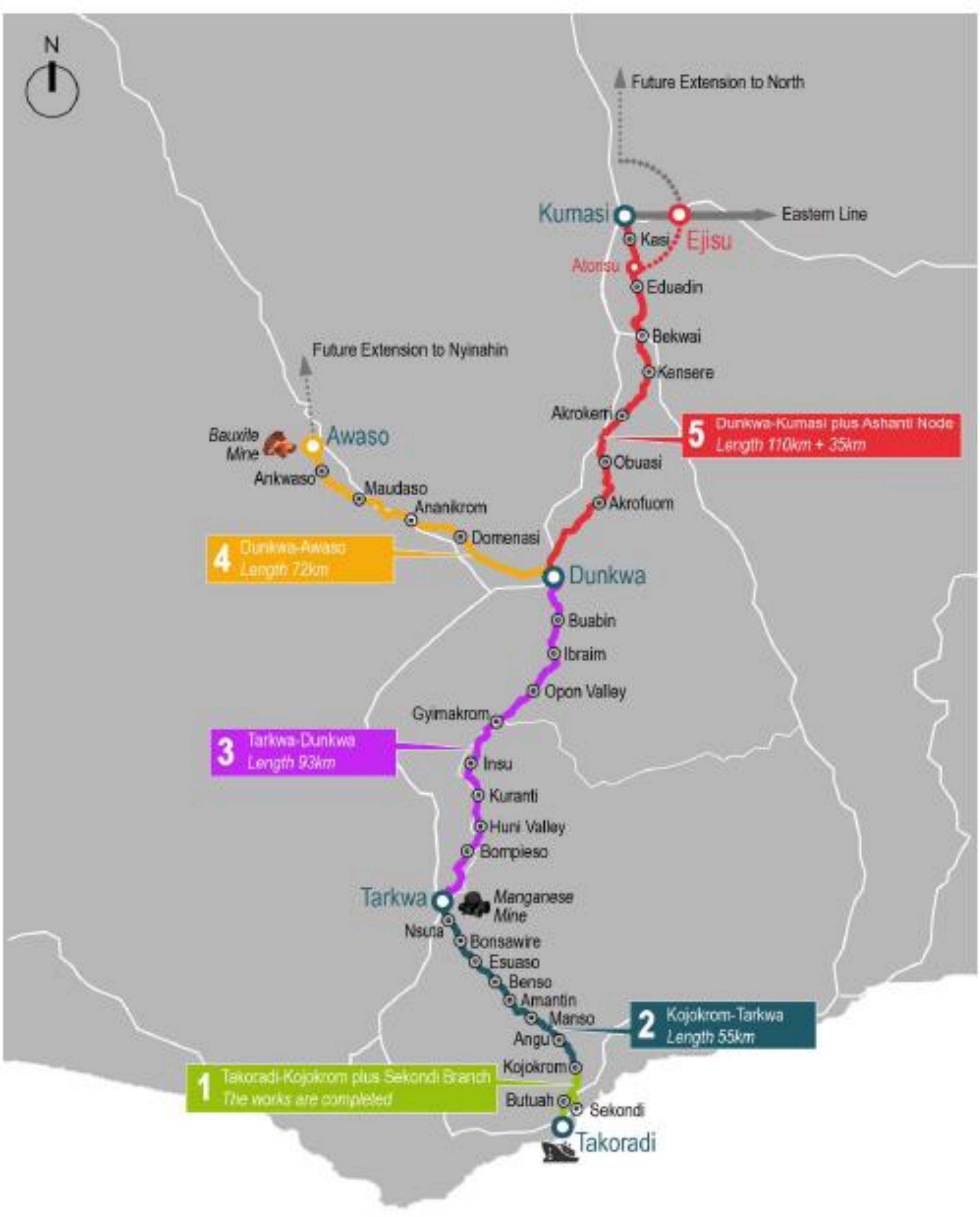


Figure 36: Western Railway Line Sections

The current transport system in Ghana depends mainly on the road network, made up of approximately 67,000km of main and secondary roads, of which approximately 12,800km are main arteries but of which only 3800km are paved. Another, more limited, contribution that has grown in recent years is water transport that takes place along the Volta Lake between the ports of Akosombo in the South and Buipe and Yapei in the North.

The existing railway network Built during the colonial period, they are narrow (Cape) gauge, single track lines and were used for both freight and passenger traffic. Over the years this railway network has deteriorated, together with the rolling stock, due to lack of maintenance and is currently in a state of disrepair and is not able to guarantee reliable and safe transport.

Evolution of the demand for freight and passenger transport in Ghana with a timeframe in 2015, year in which it is hypothesized to start the infrastructural interventions; successive developments up to 2030, year in which approximately half of the Project will have been realized, and 2047 when the foreseen interventions will be concluded;

3.2 EVOLUTION OF TRANSPORT DEMAND

The country covers an area of approximately 238,000sq.km, with a population of approximately 25 million inhabitants. The per capita gross income in 2010 was approximately 1300 US$. The annual development increase in the various sectors is between 6 and 8%.

A further economic growth is foreseen that will bring the per capita income to approximately US$ 3000by 2020. This improvement is due to, besides the economic growth in the various sectors, the new contribution from the oil and gas sectors and from the mining industry in the Southeast and Southwest of the country.

The current overall freight traffic for the entire country for 2008 was approximately 28.2 million tons/year; passenger traffic was approximately 0.64 million passengers/day. Both these figures almost exclusively refer to road transport.

Starting from this scenario, the existing O/D matrix for freight and passengers has been analyzed, which was studied and elaborated in the I.T.P. (Integrated Transport Plan) by the French engineering company Egis BCEOM and which referred to 2008; it was then up-dated according to the factors of growth and socio-economic development in the country at the various timeframes of the Project and with reference to the zoning of the country model (45 zones of which 39 within the country and 6 outside. A forecast has also been included for future development of the mining settlements indicated above and the agricultural center of Brong-Ahafo in the central region of the country (middle belt).

The following table gives the global values of traffic demand in Ghana for a certain period of time that will then be assigned to the means of transport at the various timeframes.

Table 1: Global values of traffic demand

Year	Scenario	Freight Traffic in mill.tons/year	Passenger Traffic in mill. pax/day
2008	Current	28.25	0.64
2015	Start of interventions	36.25	0.73
2030	During interventions	65.98	0.99
2047	End of interventions	128.57	1.38

The import-export traffic of goods from the ports of Tema and Takoradi completes the picture, having a total flow of respectively 14.0 and 4.0 mill.tons/year and container traffic of 750,000 and 53,000 TEU.

3.3 ASSIGNMENT OF TRANSPORT DEMAND

For the assignment of the transport demand, represented by the up-dated O/D matrix, the model takes into account, among other things, the various parameters that characterize the transport offer among which for example: transportation time, commercial speeds, tariffs, road conditions, petrol cost, etc. The model permits the assignment of traffic using the TransCAD software.

The results of the assignments of goods and passenger traffic along the main routes of the road network in 2015, in the corridors of interest for Phase 0 without the Project, and analogously still on the road network without the project in 2030 and 2047, are summarized in the following tables 2, 3and 4.

Table 2 without the Project

	Year 2015					
Main road corridors	**goods (average weight)**			**passengers (average weight)**		
	northbound	southbound	total	northbound	southbound	total
	(mil.ton./y)	(mil.ton./y)	(mil.ton./y)	$10^3 \cdot$ pax/d	$10^3 \cdot$ pax/d	$10^3 \cdot$ pax/d
Western	2.18	1.29	3.47	14.5	14.8	29.3

Table 3without the Project

	Year 2030					
Main road corridors	**goods (average weight)**			**passengers (average weight)**		
	northbound	southbound	total	northbound	southbound	total
	(mil.ton./y)	(mil.ton./y)	(mil.ton./y)	$10^3 \cdot$ pax/d	$10^3 \cdot$ pax/d	$10^3 \cdot$ pax/d
Western	3.86	2.28	6.13	19.6	19.9	39.5

Table 4without the Project

	Year 2047					
Main road corridors	**goods (average weight)**			**passengers (average weight)**		
	northbound	southbound	total	northbound	southbound	total
	(mil.ton./y)	(mil.ton./y)	(mil.ton./y)	$10^3 \cdot$ pax/d	$10^3 \cdot$ pax/d	$10^3 \cdot$ pax/d
Western	7.51	4.43	11.94	27.3	27.9	55.2

A comparison of the three tables shows how the freight and passenger traffic would increase on the roads should the Project not is carried out, as a result of the evolution of traffic demand over the years.

With the realization of the Project, the results of the assignment of freight and passenger traffic, from Phase1 to Phase 6, are summarized for the various reference years in the following Tables 5 and 6.

Table 5with the Project (Freight)

	Freight traffic (average weight) in mill.ton/year								
Railway Lines	**2015**			**2030**			**2047**		
	Northb.	Southb.	Total	Northb.	Southb.	Total	Northb.	Southb.	Total
Phase 1-Rehabilitation									
Western	0.60	1.36	1.96						
Phase 2-Central Corr.									
Western				0.95	2.70	3.66	2.10	5.79	7.89
Phase 4-Ecowas Ext.							0.43	0.12	0.55
Phase 5-Western L. Ext.							1.80	1.85	3.66
Phase 6-Eastern L. Ext.							2.47	3.08	5.55

Table 6with the Project (Passengers)

	Passenger traffic (average weight) in '000 pass/day								
Railway Lines	**2015**			**2030**			**2047**		
	Northb.	Southb.	Total	Northb.	Southb.	Total	Northb.	Southb.	Total
Phase 1-Rehabilitation									
Western	2.5	2.5	5.0						
Phase 2-Central Corr.									
Western				5.3	5.3	10.6	8.0	8.0	15.9
Phase 4-Ecowas Ext.							18.6	19.8	38.4
Phase 5-Western L. Ext.							5.0	4.9	9.9
Phase 6-Eastern L. Ext.							2.47	3.08	5.55

The assignments made with and without the realization of the Project, from Phase 1 to Phase 6, indicate that the railway traffic absorbs a significant amount of road traffic. The allocation coefficients of the traffic between the various means of transport are the following:

Table 7Freight Traffic

	Total freight traffic north and southbound (average weight) in mil. Tons/year and % absorbed from road								
Railway Lines	**2015**			**2030**			**2047**		
	a) tot.Tab.1	**b) tot.Tab.4**	**c) % dren.**	**a) tot.Tab.2**	**b) tot.Tab.4**	**c) % dren.**	**a) tot.Tab.3**	**b) tot.Tab.4**	**c) % dren.**
Phase 1 - rehabilitation									
Western	3.47	1.96	56%						
Phase2 -Central Corridor									
Western	3.47			6.13	3.66	60%	11.94	7.89	66%
Phase 3 -Transv. Links									
Phase 4 -Ext. Ecowas Line	1.50			2.68			5.23	0.55	11%
Phase 5 - Ext.Western Line	1.33			2.38			4.65	3.66	79%
Phase 6 -Ext. Easter Line	0.6			1.08			2.10	5.55	264%
							B	**16.64**	**34%**
							A+B	**48.90**	**100%**

Table 8Passenger Traffic

	Total passenger traffic north and southbound (average weight) in '000 pass/day and % absorbed from road								
Railway Lines	**2015**			**2030**			**2047**		
	a) tot.Tab.1	**b) tot.Tab.5**	**c) % dren.**	**a) tot.Tab.2**	**b) tot.Tab.5**	**c) % dren.**	**a) tot.Tab.3**	**b) tot.Tab.5**	**c) % dren.**
Phase 1 - rehabilitation									
Western	29.3	5.00	17%						
Phase2 -Central Corridor									
Western	29.3			39.50	10.60	27%	55.20	15.90	29%
Phase 3 -Transv. Links									
Phase 4 -Ext. Ecowas Line	46.0			61.70			86.80	38.40	44%
Phase 5 - Ext.Western Line	8.0			11.10			15.00	9.90	66%
Phase 6 -Ext. Easter Line	12.3			15.60			23.20	24.00	103%
							D	**91.50**	**33%**
							C+D	**274.20**	**100%**

The Rehabilitation and Modernization of the existing infrastructure will consist in:

- Increasing the minimum curve radii;
- Decrease the maximum gradients compensated in the direction of trains loaded with minerals;
- Increase the axle load
- Reinforce the permanent way;
- Reconstruct existing bridges and culvers due to the increase in axle load;
- Lengthen passing loop lengths in stations and junctions to be compatible with the forecasted lengths of the trains

The objectives of the Rehabilitation are to:

- increase line capacity;
- increase average speed/reduce travel time;
- increase passenger comfort,
- Increase efficiency/reduce maintenance costs.

The following table shows the length of the existing rail lines that will be rehabilitated and the total length of the relative routes.

Table 9Rehabilitation of Existing Rail Lines

PHASE 1	
Western Line (1 W)	
1- Takoradi - Kumasi	266,8
2- Dunkwa - Awaso	73,2
	340.0
Eastern Line (1 E)	
Accra - Kumasi	303,9
Achimota - Tema	23.70
	327.60
Total Km	**667.6**

3.4 TRAFFIC SIMULATION

The traffic volumes simulations for freight and passengers have been operated through the TransCAD model, assigning the freight and passenger transport demand (ITP O/D matrices) on the Multi-modal graph. In particular the ITP matrices have been updated with additional information, while, for lack of project data, the Volta Lake transport is supposed in the future to absorb the entire traffic in petroleum products, which is excluded from the present ITP matrices.

The Assignment model assigns traffic flows between Origins and Destinations according to minimum generalized cost of transport, which includes transport operating costs and time spent along the routes. It is assumed that cargo and passengers will chose the most convenient route from the cost and time point of view.

The Master Plan Project phases adopted are the following:

- Phase 0: Without Project Scenario: Cargo & Passengers;
- Phase 1: Rehabilitation of Existing lines NG:
  - 1W Western line:
  - 1E Eastern line;
- Phase 2: Central Spine Expansion SG:
  - 2W Western line,
  - 2E Eastern line
  - 2C Kumasi-Paga line;
- Phase 3 - Transversal Expansions SG:
  - 3.1 Tamale – Yendi,
  - 3.2 Fufulsu - Sawla,
  - 3.3 Techiman - Kwadwokurom,
  - 3.4 Nyinahin - Kumasi;
- Phase 4 - Trans-ECOWAS Expansion SG: Aflao-Accra-Takoradi-Omanpe line;
- Phase 5 – Western Expansion SG: Dunkwa-Awaso-Hamile line;
- Phase 6 – Eastern Expansion SG: Tema-Yendi-Tamale line.

I will just show result of the freight and passenger simulation for 2015 and 2047 with assigning the project and the rest of the simulation will be presented in the appendix.

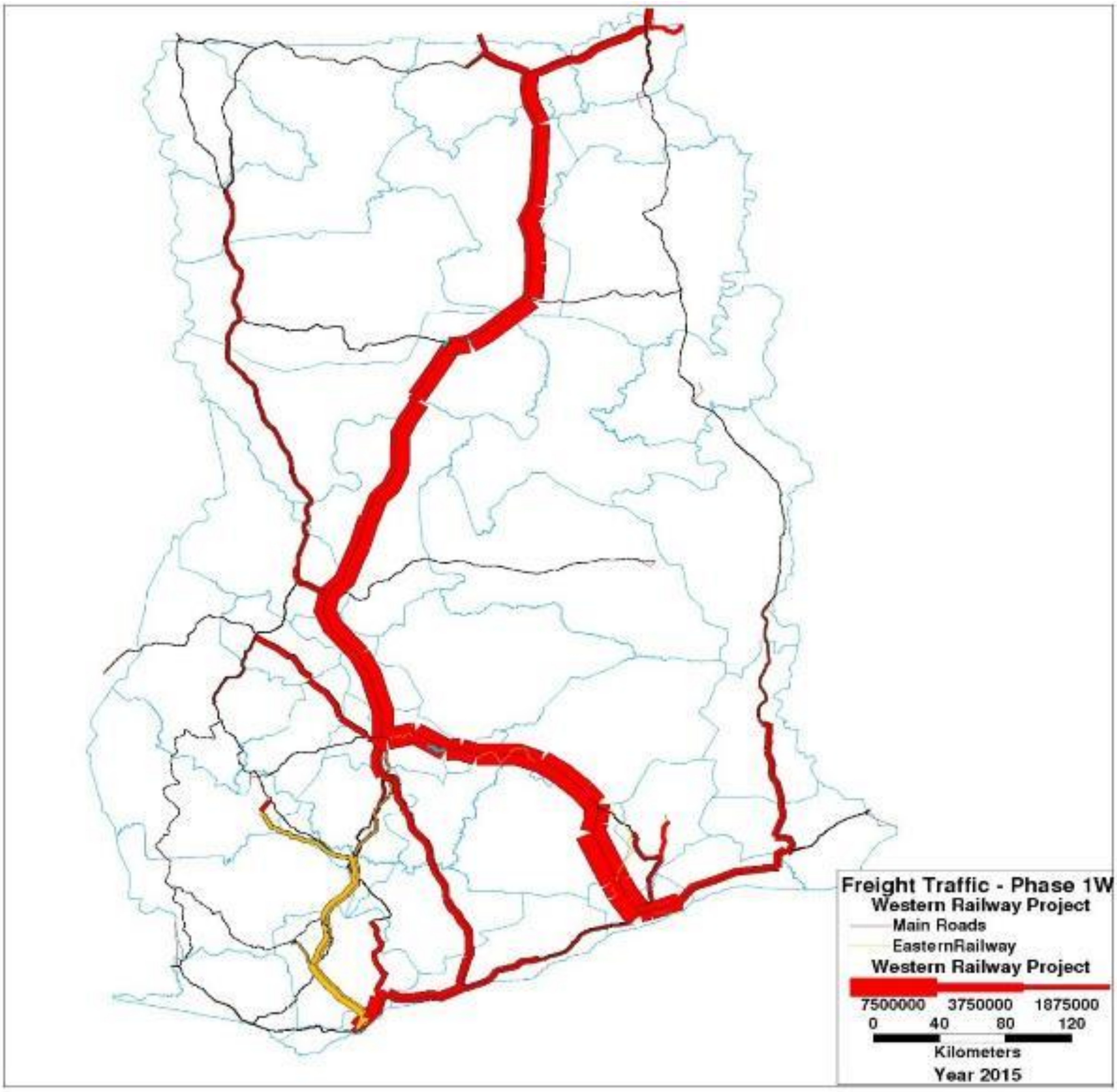


Figure 37: Freight Traffic 2015 – Phase 1W Western Railway Project

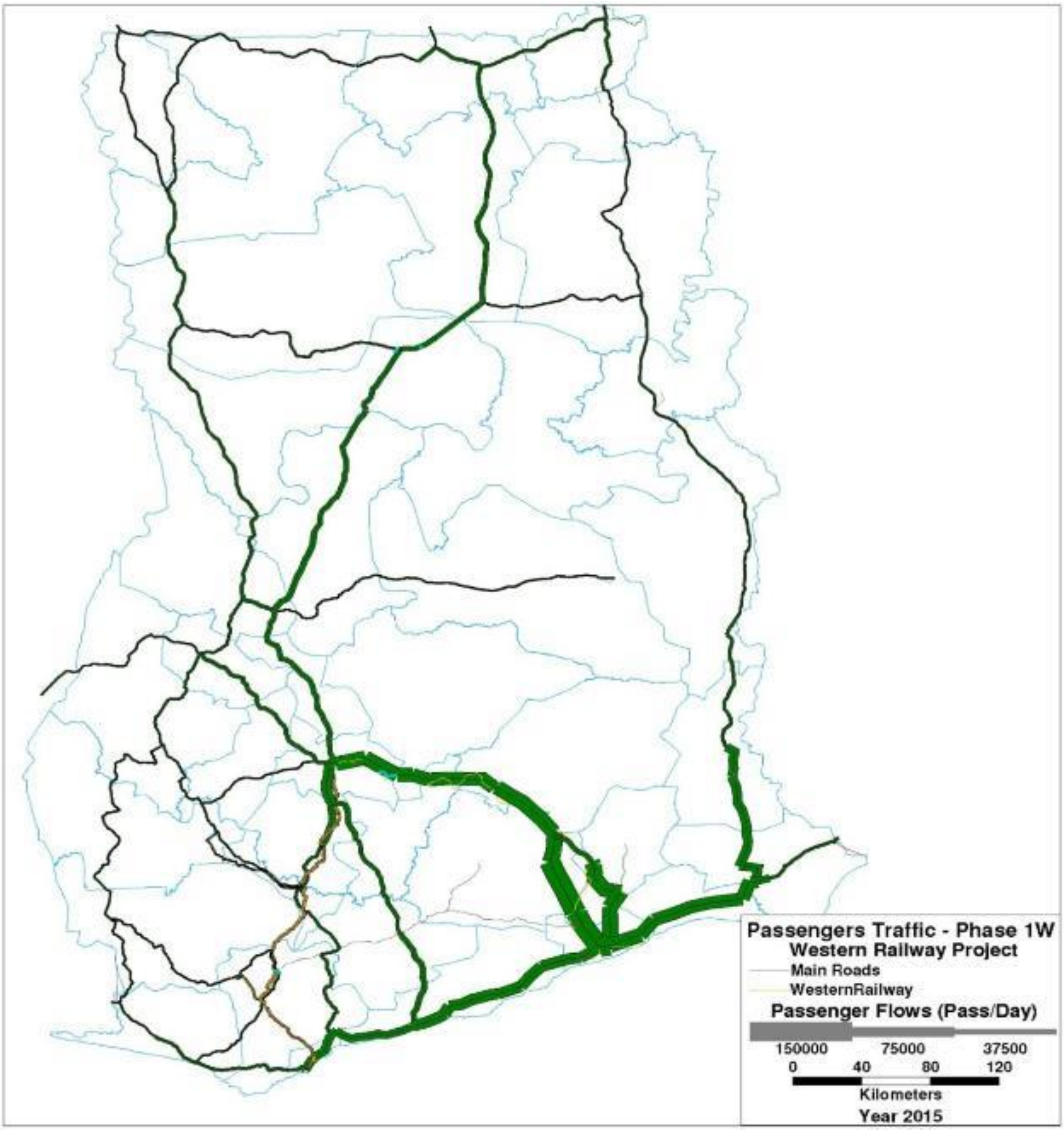


Figure 38: Passengers Traffic 2015 – Phase 1W Western Railway Project

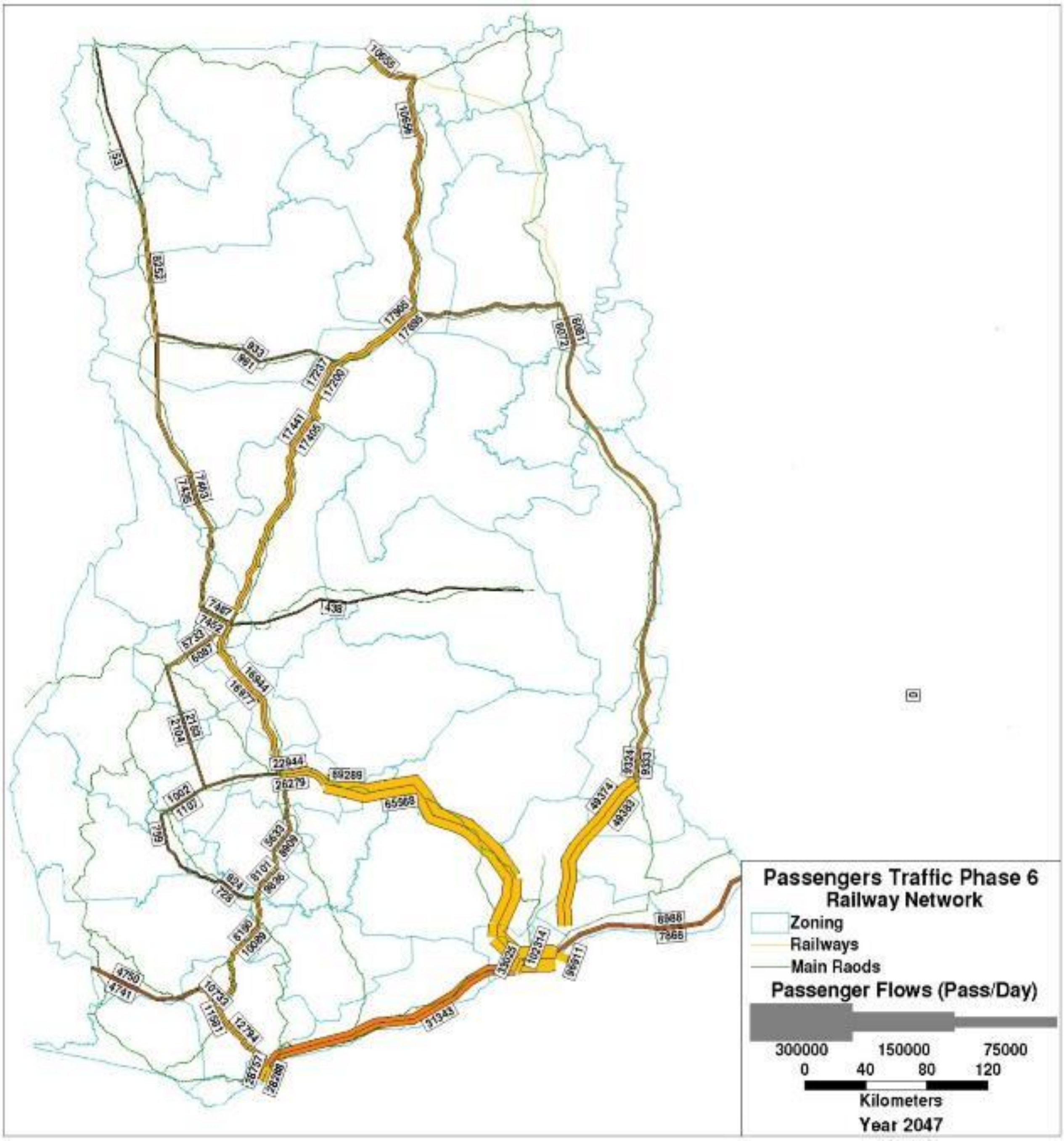


figure 39:Railway Passengers Traffic 2047 – Phase 6

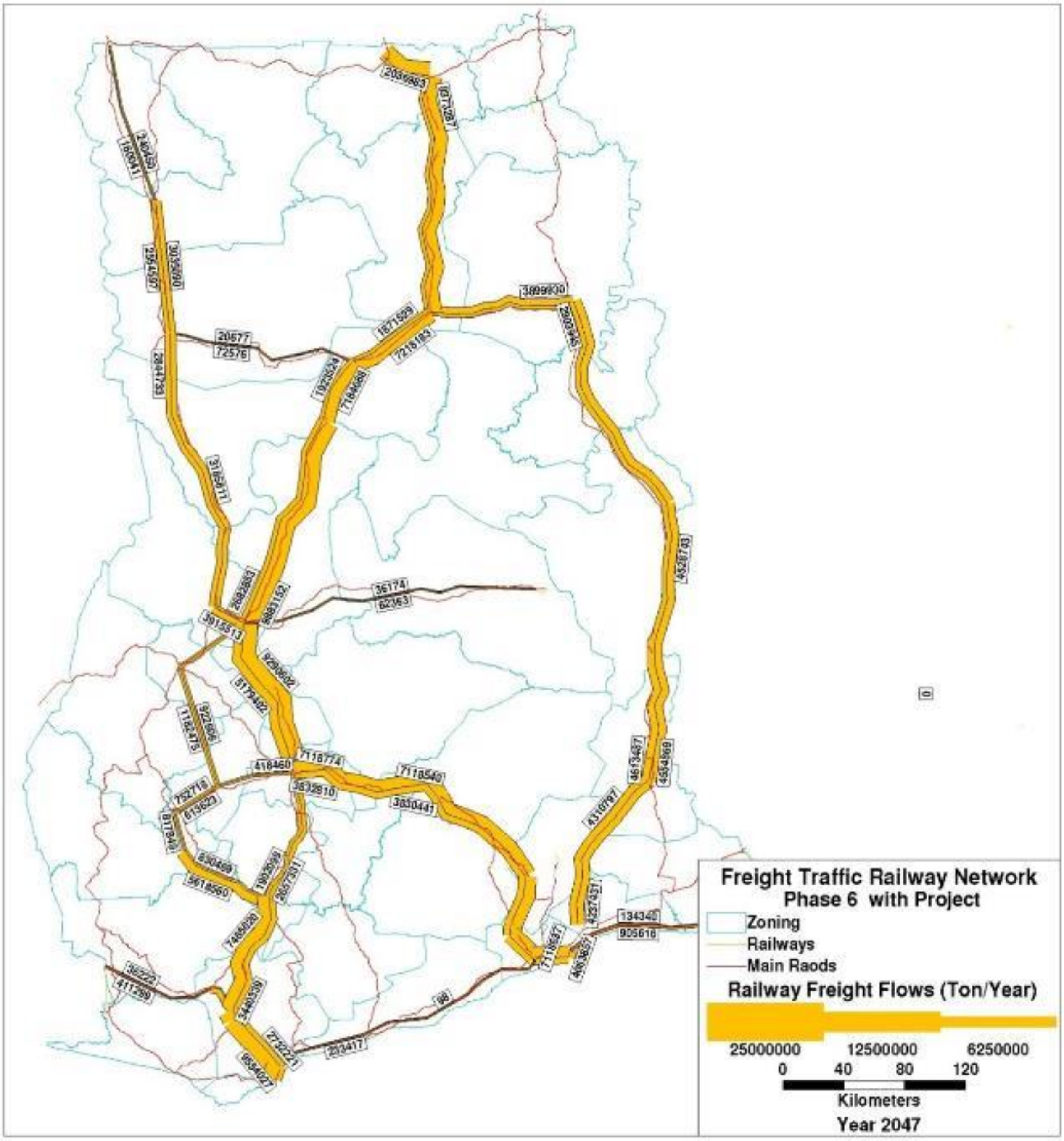


Figure 40: Railway Freight Traffic 2047 – Phase 6

According to the Ghana Railway Master Plan carried out by TEAM in 2013, the following table gives the global values of traffic demand in Ghana for the means of transport at the various timeframes.

Table 10: Evolution of transport demand

Year	Scenario	Freight Traffic (10^6 ton/year)	Passenger Traffic (10^3 pass/day)
2015	Start of analysis	36.25	730
2030	Medium term	65.98	990
2047	Long term	128.57	1,380

Over the years this railway network has deteriorated, together with the Rolling Stock, due to lack of maintenance and is currently in a state of disrepair and is not able to guarantee reliable and safe transport

Accordingly, the figures below show the peak performances reached in 1965 for freight traffic and in 1971 for passenger traffic, but ineffective management combined with lack of funding have brought to the subsequent deterioration of the whole system and to a drastic reduction of traffic.

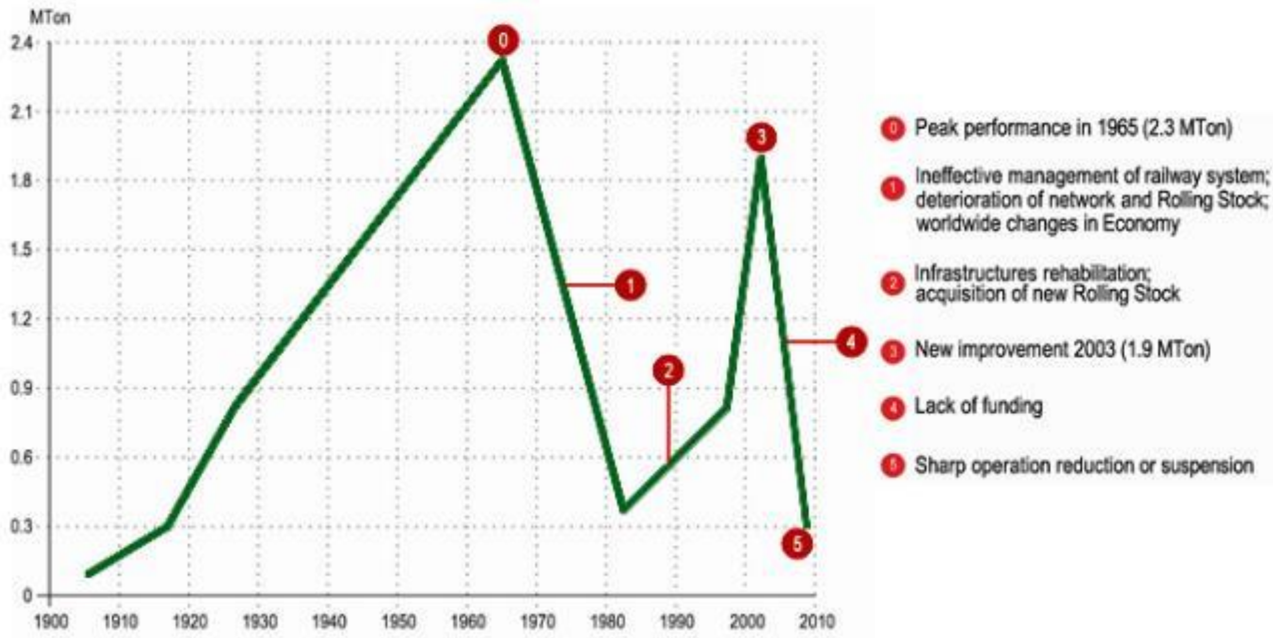


Figure 41: Rail Freight Traffic Evolution

(Source: Ghana News Agency; GRCL 2008)

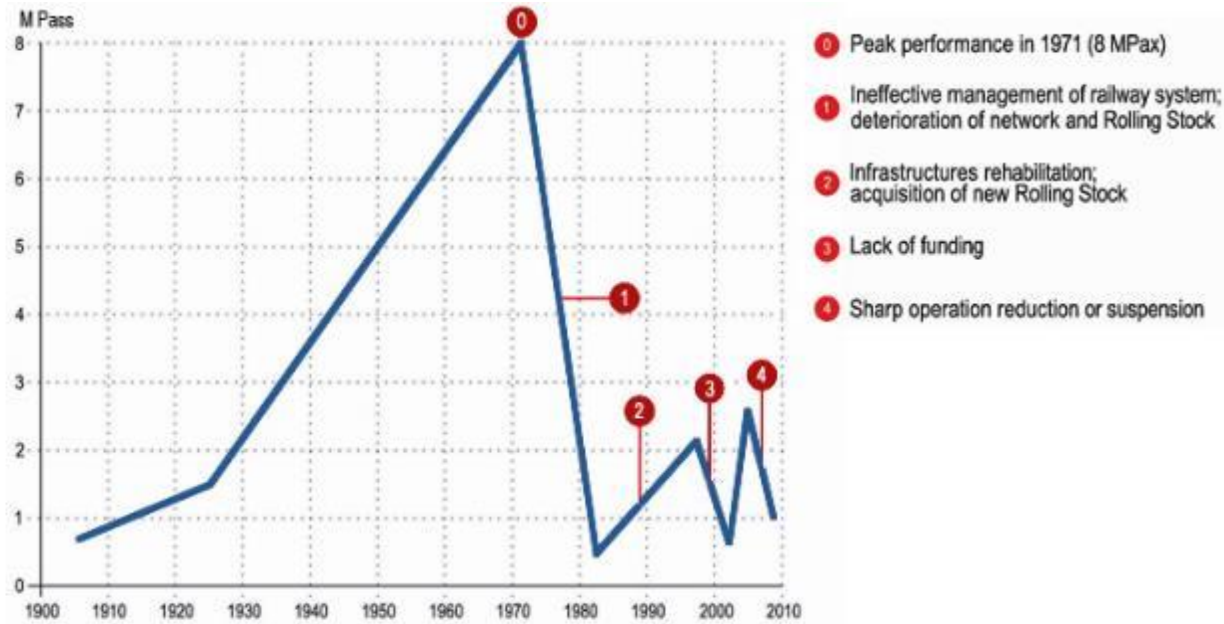


Figure 42: Rail Passenger Traffic Evolution

(Source: Ghana News Agency; GRCL 2008)

3.5 OPENTRACK SOFTWARE

OpenTrack began in the mid-1990s as a research project at the Swiss Federal Institute of Technology. The aim of the project Object-Oriented Modeling in Railways, was to develop a catalyst for practical economic solutions to complex railway technology problems.(19)

OpenTrack describes a railway network in special graphs called double vertex graphs. A user can edit the network's topology graphically. Every element of the graph holds various attributes. An edge, for example, holds its length, the gradient, the maximum speed for different train categories and much more. A user can create and manage objects for edges and vertices, and also signals, switches, stations and routes. The following figure shows part of a topology. (19)

The following figure shows how the simulation tool works. Predefined trains run according to the timetable on a railway network. During the simulation, OpenTrack calculates train movements under the constraints of the signaling system and timetable. After a simulation run, OpenTrack can analyze and display the resulting data in the form of diagrams, train graphs, occupation diagrams and statistics.(19)

OpenTrack handles single simulation runs as well as multiple simulation runs where random generators produce different initial delays and station delays.

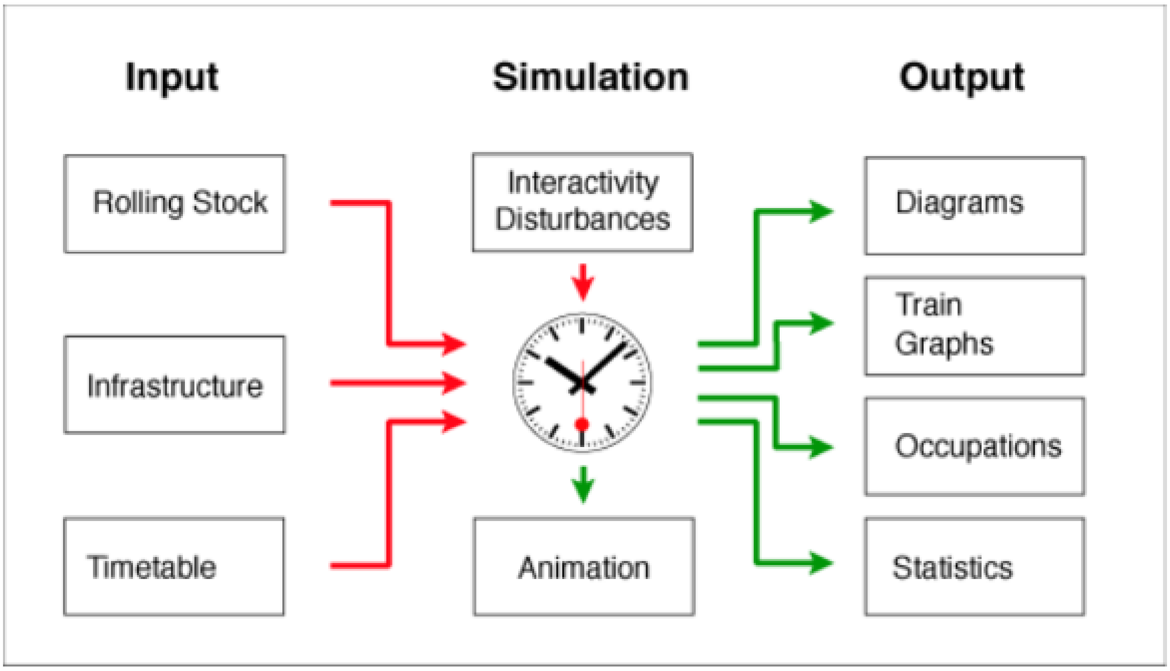


Figure 43: input and output of the simulation

During the simulation, trains try to obey the given timetable. The differential equations for speed and distance are the basis for calculating a train's movement. The signaling system of the railway network poses constraints. Occupied tracks and restrictive signal aspects may impede a train's progress.(19)

After a simulation, OpenTrack offers a number of evaluations. Evaluations of a train, line or station are possible. For a train, OpenTrack offers diagrams such as acceleration vs. distance, speed vs. distance, and obstructions. For a line, there are evaluations in the form of diagrams of train movements, route occupation and line profiles. Every station produces output about all the trains that used it, including arrival, stopping and departure times.(19)

In this thesis the OpenTrack used to give the result of the changing characteristic of the line and finding and comparing the delay according each test established by Minitab.

3.6 MINITAB SOFTWARE

Minitab and accordingly Taguchi method is used for the simplification the experiment and testing some characters that effecting on railway and showing the result that which character has more effect on the railway line.

Minitab, originally intended as a tool for teaching statistics, is a general-purpose statistical software package designed for easy interactive use. Minitab is well suited for instructional applications, but is also powerful enough to be used as a primary tool for analyzing research data.

Design of Experiments (DOE) techniques can determine the individual and interactive effects of various factors that can influence the output results of your measurements. You can also use DOE to gain knowledge and estimate the best operating conditions of a system, process or product.(20)

The Design of Experiments (DOE, DOX, or experimental design) is the design of any task that aims to describe or explain the variation of information under conditions that are hypothesized to reflect the variation. The term is generally associated with true experiments in which the design introduces conditions that directly affect the variation, but may also refer to the design of quasi-experiments, in which natural conditions that influence the variation are selected for observation.

In 1972 three Penn state professors created MINITAB statistical software to more easily teach their students statistics. The application performed the calculation, and allowed student to focus on learning the concepts and what they can reveal about the world.

A Taguchi design is a designed experiment that lets you choose a product or process that function more consistently in the operating environment. Taguchi designs recognize that not all factors that caused variability can be controlled. These uncontrollable factors are called noise factors. Taguchi designs try to identify controllable factors (control factors) that minimize the effect of the noise factors. You can also add a signal factor to the Taguchi design to create a dynamic response experiment. A dynamic response experiment is used to improve the functional relationship between a signal and an output response.

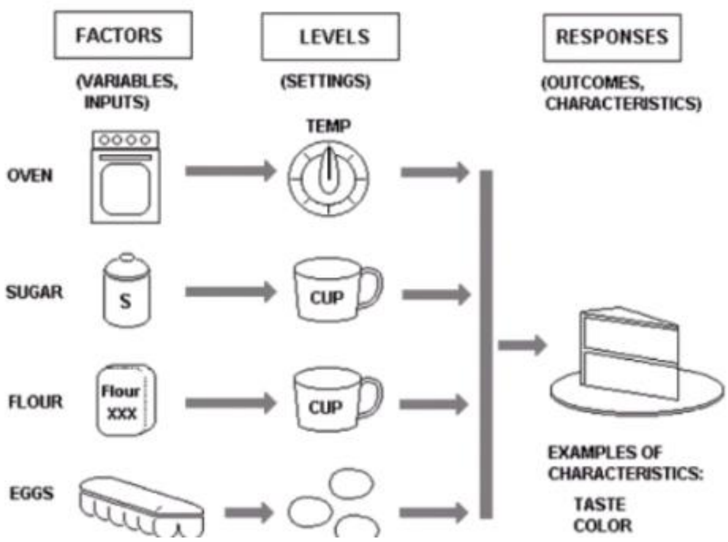


Figure 44: Taguchi Design

3.6.1 Engineering Experiments

If we had infinite time and resource budgets there probably wouldn't be a big fuss made over designing experiments. In production and quality control we want to control the error and learn as much as we can about the process or the underlying theory with the resources at hand. From an engineering perspective we're trying to use experimentation for the following purposes:(21)

- reduce **time** to design/develop new products & processes
- improve **performance** of existing processes
- improve **reliability** and performance of products
- achieve product & process **robustness**
- Perform **evaluation** of materials, design alternatives, **setting** component & system tolerances, etc.

Replication is some in sense the heart of all of statistics. To make this point Remember what the standard error of the mean is? It is the square root of the estimate of the variance of the sample mean, i.e., $\sqrt{S^2}/n$. The width of the confidence interval is determined by this statistic. Estimation of the mean becomes less variable as the sample size increases.
Replication is the basic issue behind every method we will use in order to get a handle on how precise our estimates are at the end. We always want to estimate or control the uncertainty in our results. We achieve this estimate through replication. Another way we can achieve short confidence intervals is by reducing the error variance itself. However, when that isn't possible, we can reduce the error in our estimate of the mean by increasing n.
Another way is to reduce the size or the length of the confidence interval is to reduce the error variance - which brings us to blocking.(21)

Blocking is a technique to include other factors in our experiment which contribute to undesirable variation. Much of the focus in this class will be to creatively use various blocking techniques to control sources of variation that will reduce error variance. For example, in human studies, the gender of the subjects is often important factor. Age is another factor affecting the response. Age and gender are often considered nuisance factors which contribute to variability and make it difficult to assess systematic effects of a treatment. By using these as blocking factors, you can avoid biases that might occur due to differences between the allocations of subjects to the treatments, and as a way of accounting for some noise in the experiment. We want the unknown error variance at the end of the experiment to be as small as possible. Our goal is usually to find out something about a treatment factor (or a factor of primary interest), but in addition to this we want to include any blocking factors that will explain variation.(21)

Multi-factor Designs: we will spend at least half of this course talking about multi-factor experimental designs: 2^k designs, 3^k designs, response surface designs, etc. The point to all of these multi-factor designs is contrary to the scientific method where everything is held constant except one factor which is varied. The one factor at a time method is a very inefficient way of making scientific advances. It is much better to design an experiment that simultaneously includes combinations of multiple factors that may affect the outcome. Then you learn not only about the primary factors of interest but also about these other factors. These may be blocking factors which deal with nuisance parameters or they may just help you understand the interactions or the relationships between the factors that influence the response.(21)

3.6.2 Taguchi Method

Taguchi method is a statistical method developed by Taguchi and Konishi. Initially it was developed for improving the quality of goods manufactured (manufacturing process development), later its application was expanded to many other fields in Engineering, such as Biotechnology etc. Professional statisticians have acknowledged Taguchi's efforts especially in the development of designs for studying variation. Success in achieving the desired results involves a careful selection of process parameters and bifurcating them into control and noise factors. Selection of control factors must be made such that it nullifies the effect of noise factors. Taguchi Method involves identification of proper control factors to obtain the optimum results of the process. Orthogonal Arrays (OA) are used to conduct a set of experiments. Results of these experiments are used to analyze the data and predict the quality of components produced.(22)

The Full Factorial Design requires a large number of experiments to be carried out as stated above. It becomes laborious and complex, if the number of factors increase. To overcome this problem Taguchi suggested a specially designed method called the use of orthogonal array to study the entire parameter space with lesser number of experiments to be conducted. Taguchi thus, recommends the use of the loss function to measure the performance characteristics that are deviating from the desired target value. The value of this loss function is further transformed into signal-to-noise (S/N) ratio. Usually, there are three categories of the performance characteristics to analyze the S/N ratio. They are: nominal-the-best, larger-the-better, and smaller-the-better.(22)

Table 11shows the L9 orthogonal array in three level and the porosity measurements the team took.

Table 11: Orthogonal array (source: www.ecs.umass.edu)

L_9 (3^4) Orthogonal array					
	Independent Variables				Performance Parameter Value
Experiment #	Variable 1	Variable 2	Variable 3	Variable 4	
1	1	1	1	1	p1
2	1	2	2	2	p2
3	1	3	3	3	p3
4	2	1	2	3	p4
5	2	2	3	1	p5
6	2	3	1	2	p6
7	3	1	3	2	p7
8	3	2	1	3	p8
9	3	3	2	1	p9

I will have two examples to clarify this method and I will start with the definition of the signal and noise, for example in the ceramic factory because of the malfunction of the chimney, the sizes of mosaic tiles are not unique. The price of changing the chimney is too much engineers understand the lime can confront with this defect. So the chimney is noise and lime is control factor. For the second example I will explain the method of the DOE, if we want to know the effect of the 4fertilizer on a land we divide the land into the 4 column and 4 rows and we use each fertilizer one time in each column and each rows, so with this method we can understand the effect fertilizer with minimum impact of the land change impact.

Chapter 4
Data Collection and Analysis

I used OpenTrack simulator for the simulation of several parameters and finding which parameters have more effect in railway design for this reason I will explain a little about the OpenTrack must useful parts.

Locomotive data is stored in a database called Depot. This database describes all possible locomotive types in terms of technical specifications such as: tractive effort/speed diagram, weight, length, and adhesive values.

Infrastructure related train operations terms are user defined combinations of physical elements that are logical to group together. These terms are associated with the infrastructure and do not have movement information (i.e. schedules) associated with them. There are three levels of infrastructure related terms, higher levels consist of sets of the lower level. Specifically:

• Route - Routes are the first level of train movement description. They consist of a set of vertexes and edges which are linked together. In physical terms they can be thought of as sections of track.

• Path - Paths are the second level, they consist of sets of Routes. In physical terms they can be thought of as a group of track sections in a certain area, for example, a group of track sections that a train would use to pass through a station.

• Itinerary - Itineraries are the third level, they consist of a sets of Paths. The station area generally encompasses the area from the entry signal on one side to the entry signal on the other side of the station. Figure 20 illustrates this type of station area.

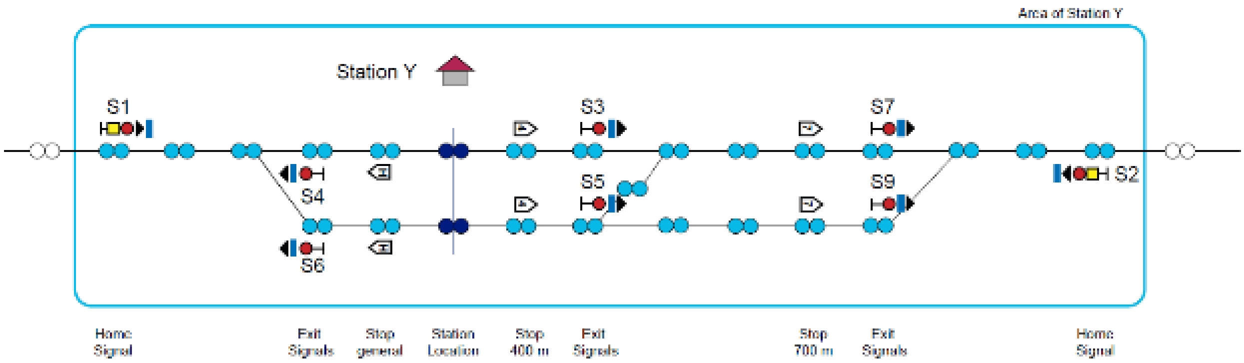


Figure 45: Station Area

The station vertices must be set in such a way that each path through the station passes through exactly one station vertex. The station vertex represents the kilometer reference point from the station database on the OpenTrack worksheet. (The station database information is generally from the railroad's infrastructure department and represents the location of the station building.)

In addition to its use as a geographic reference point, the station vertex is displayed on evaluations made with OpenTrack such as the graphical timetable.

Shunting movements are movements within stations that involve a change of direction. OpenTrack defines shunting as a special type of Route. Shunting movements within a station area are modelled by means of shunting, which consist of an order of vertices of one direction of travel.

Creating an overlap means that routes are not released immediately following passage of a train. When an overlap has been created it means that, if a train comes to a halt, say for a station stop, the overlap route is not released immediately, but only after a user defined overlap release time (Release Time).

Connections can also be used to model occupied entry into a station track. In an occupied entry a train uses a station track already occupied by another train. In order to allow occupied entry, the track's home signal must explicitly allow an occupied entry by means of a corresponding signal indication (a signal aspect). The entry speed for occupied entries is reduced; the reduced speed is also a signal attribute that can be set by the user.

I used Minitab L9 orthogonal table with exporting the Taguchi model for finding the most critical parameters between speed, station distance and number of tracks.

Table 12: Minitab suggest orthogonal L9

	Level 1	Level 2	Level 3
speed	80	120	160
station distance	2	4	6
number of tracks	1	2	4

Table 13: Taguchi orthogonal table in Minitab

	speed	station distance	number of tracks
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 14: the assign experiment

	speed	station distance	number of tracks
1	80	2	1
2	80	4	2
3	80	6	4
4	120	2	2
5	120	4	4
6	120	6	1
7	160	2	4
8	160	4	1
9	160	6	2

In below I will show the result of each experiment.

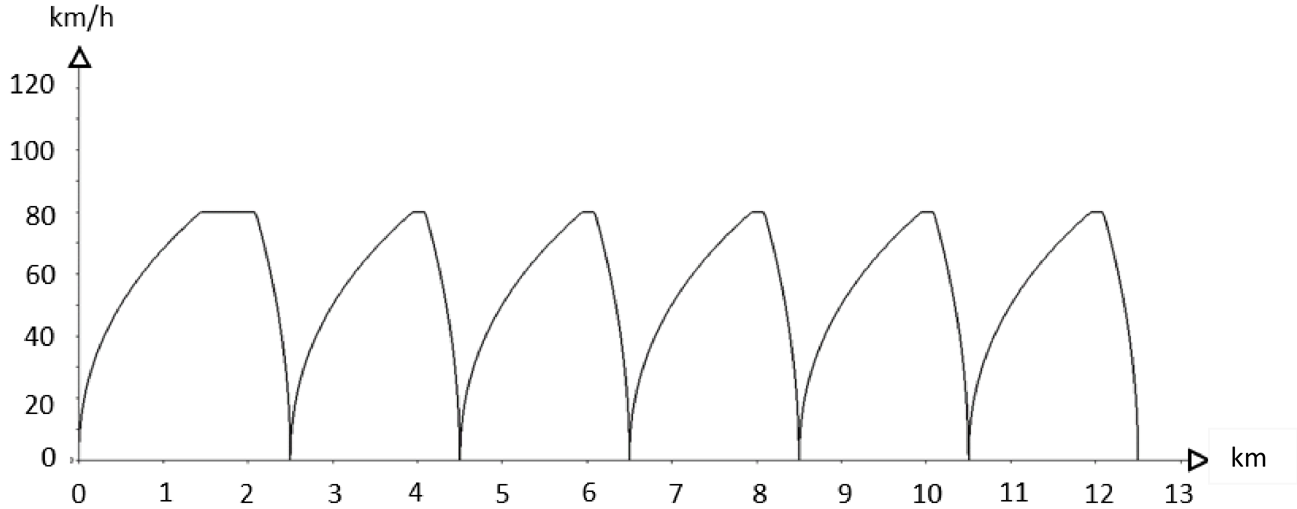


Figure 46: Speed-Distance diagram for the first test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course05	STA_1	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course05	STA_2	08:13:02	08:13:06	HH:MM:SS	08:14:06	60	✓	0
course05	STA_3	08:16:04	08:16:50	HH:MM:SS	08:19:54	60	✓	0
course05	STA_4	08:19:07	08:22:38	HH:MM:SS	08:23:38	60	✓	0
course05	STA_5	08:22:09	08:26:22	HH:MM:SS	08:27:22	60	✓	0
course05	STA_6	08:25:12	08:30:06	HH:MM:SS	08:31:49	60	✓	0
course05	STA_7	08:28:14	08:34:33	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 47: fifth course timetable and delay for first test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course06	STA_7	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course06	STA_6	08:13:02	08:13:11	HH:MM:SS	08:14:11	60	✓	0
course06	STA_5	08:16:04	08:16:50	HH:MM:SS	08:19:54	60	✓	0
course06	STA_4	08:19:07	08:22:38	HH:MM:SS	08:23:38	60	✓	0
course06	STA_3	08:22:09	08:26:22	HH:MM:SS	08:27:22	60	✓	0
course06	STA_2	08:25:12	08:30:06	HH:MM:SS	08:31:56	60	✓	0
course06	STA_1	08:28:14	08:34:40	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 48: sixth course timetable and delay for first test

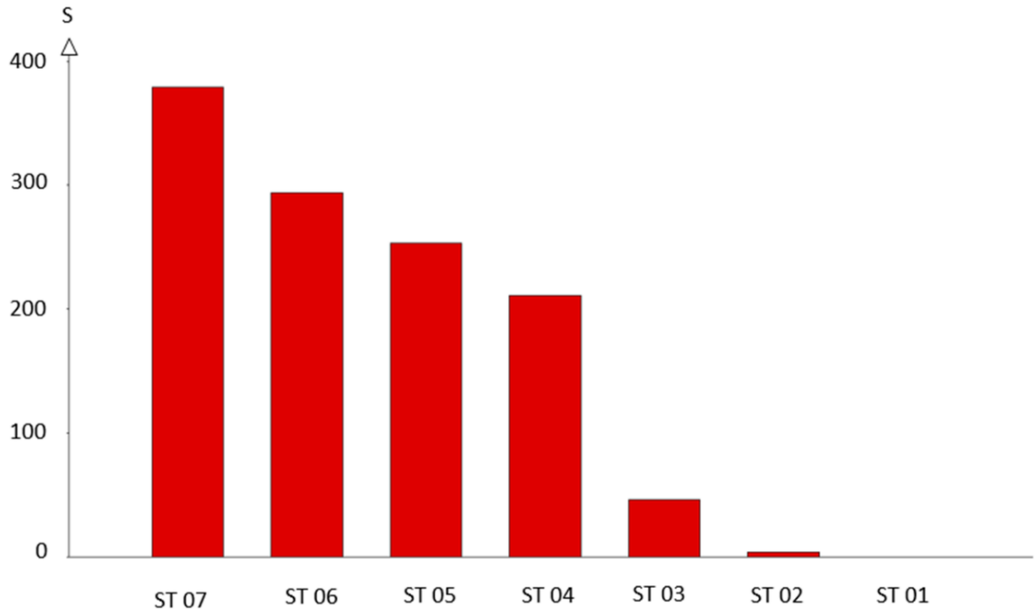


Figure 49: Delay for the first test

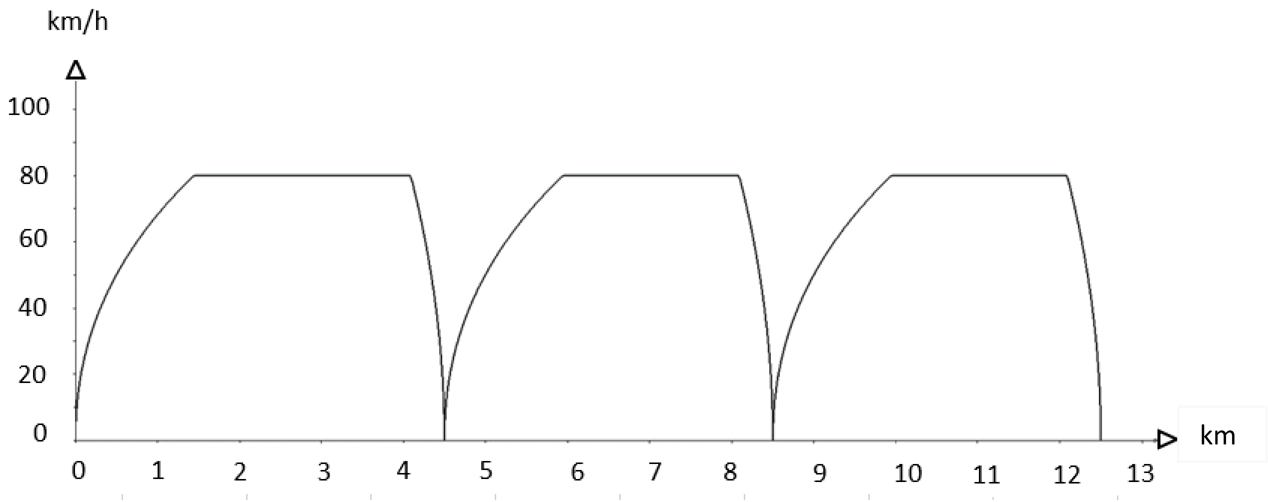


Figure 50: Speed-Distance diagram for the second test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course05	STA_1	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course05	STA_2	08:14:32	08:14:36	HH:MM:SS	08:15:36	60	✓	0
course05	STA_3	08:19:04	08:19:50	HH:MM:SS	08:20:50	60	✓	0
course05	STA_4	08:23:37	08:25:04	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 51: fifth course timetable and delay for second test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course06	STA_4	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course06	STA_3	08:14:32	08:14:36	HH:MM:SS	08:15:36	60	✓	0
course06	STA_2	08:19:04	08:19:50	HH:MM:SS	08:20:50	60	✓	0
course06	STA_1	08:23:37	08:25:04	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 52: sixth course timetable and delay for second test

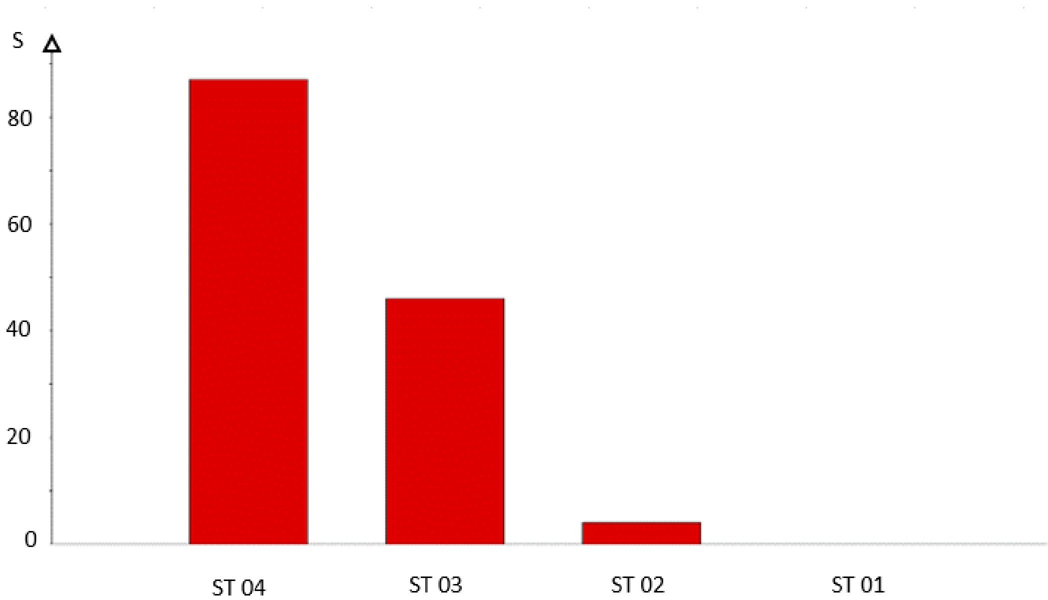


Figure 53: Delay for the second test

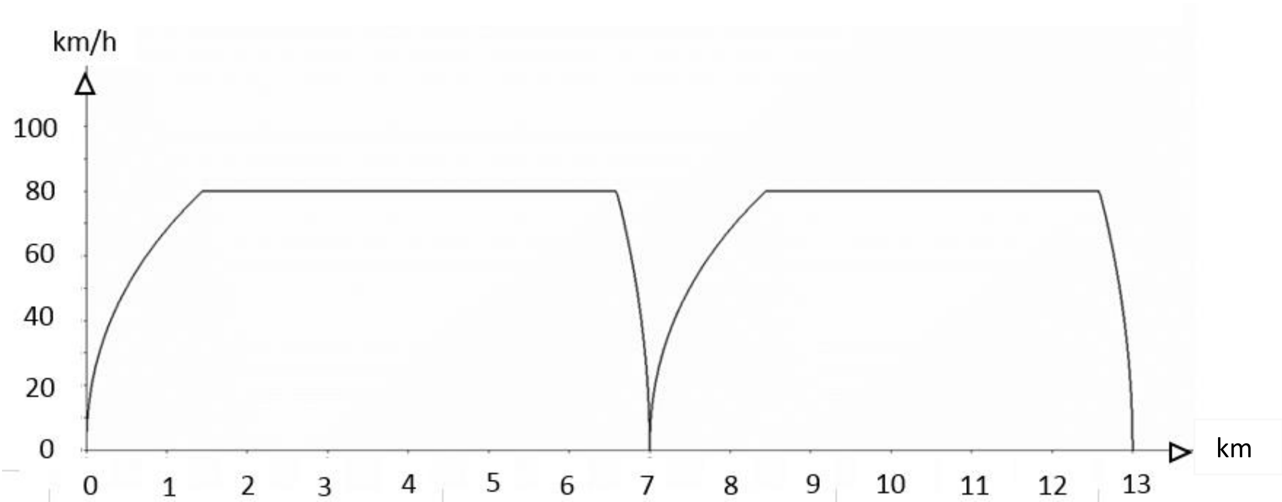


Figure 54: Speed-Distance diagram for the third test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course05	STA_1	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course05	STA_2	08:16:02	08:16:29	HH:MM:SS	08:17:29	60	✓	0
course05	STA_3	08:22:04	08:23:13	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 55: third course timetable and delay for third test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course06	STA_3	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course06	STA_2	08:16:02	08:16:29	HH:MM:SS	08:17:29	60	✓	0
course06	STA_1	08:22:04	08:23:13	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 56: Forth course timetable and delay for third test

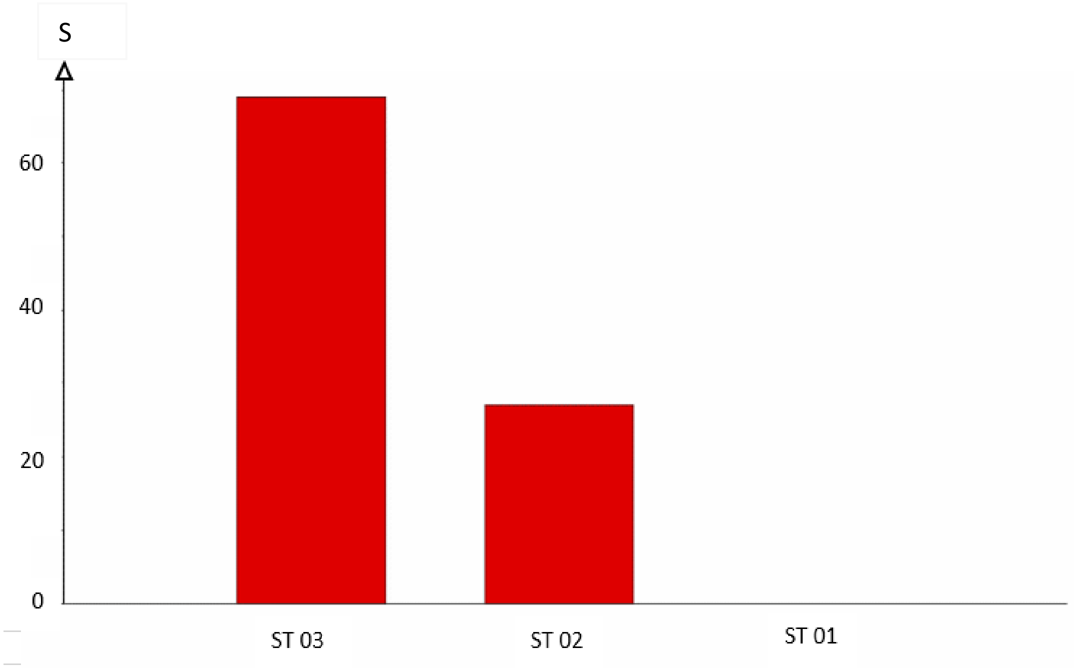


Figure 57: Delay for the third test

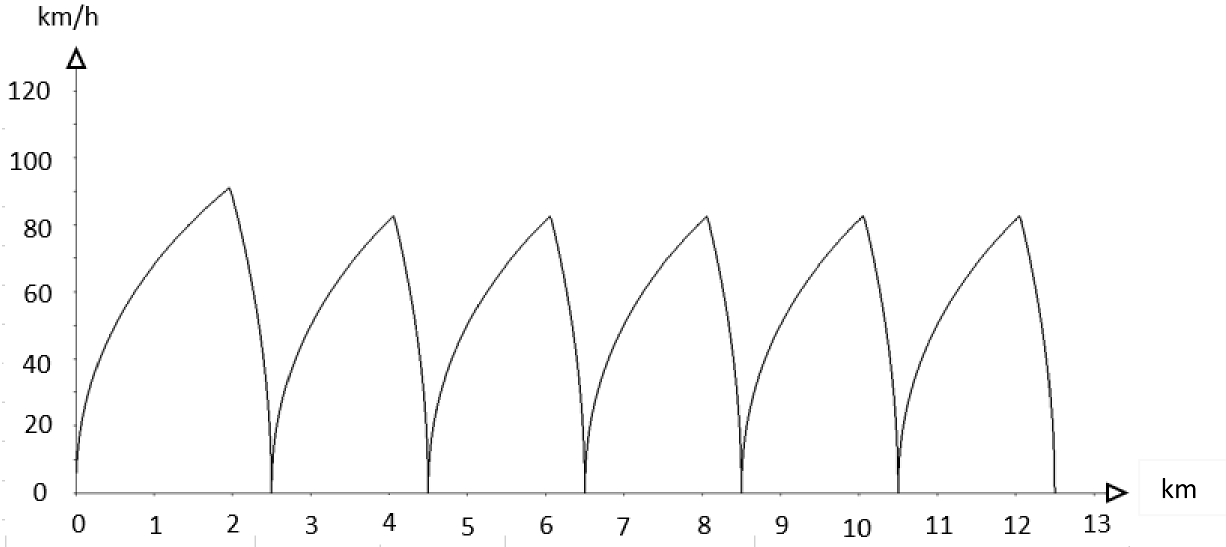


Figure 58: Speed-Distance diagram for the forth test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course05	STA_1	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course05	STA_2	08:12:48	08:13:05	HH:MM:SS	08:14:05	60	✓	0
course05	STA_3	08:15:37	08:16:49	HH:MM:SS	08:17:49	60	✓	0
course05	STA_4	08:18:25	08:20:33	HH:MM:SS	08:21:33	60	✓	0
course05	STA_5	08:21:14	08:24:17	HH:MM:SS	08:25:17	60	✓	0
course05	STA_6	08:24:03	08:28:01	HH:MM:SS	08:29:01	60	✓	0
course05	STA_7	08:26:51	08:31:45	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 59: fifth course timetable and delay for forth test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course06	STA_7	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course06	STA_6	08:12:48	08:13:05	HH:MM:SS	08:14:05	60	✓	0
course06	STA_5	08:15:37	08:16:49	HH:MM:SS	08:17:49	60	✓	0
course06	STA_4	08:18:25	08:20:33	HH:MM:SS	08:21:33	60	✓	0
course06	STA_3	08:21:14	08:24:17	HH:MM:SS	08:25:17	60	✓	0
course06	STA_2	08:24:03	08:28:01	HH:MM:SS	08:29:01	60	✓	0
course06	STA_1	08:26:51	08:31:45	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 60: sixth course timetable and delay for forth test

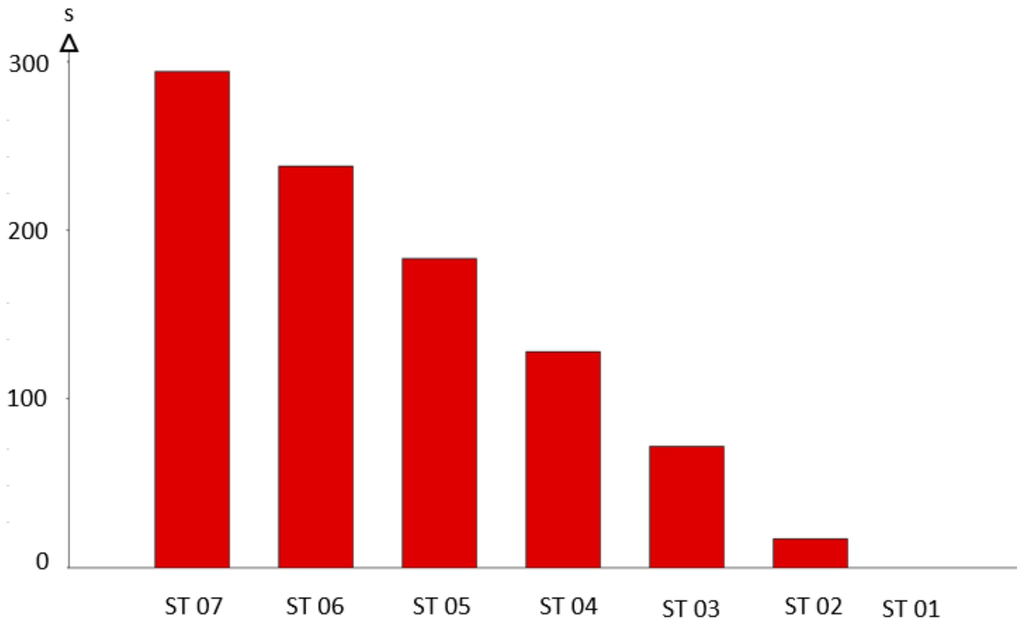


Figure 61: Delay for the forth test

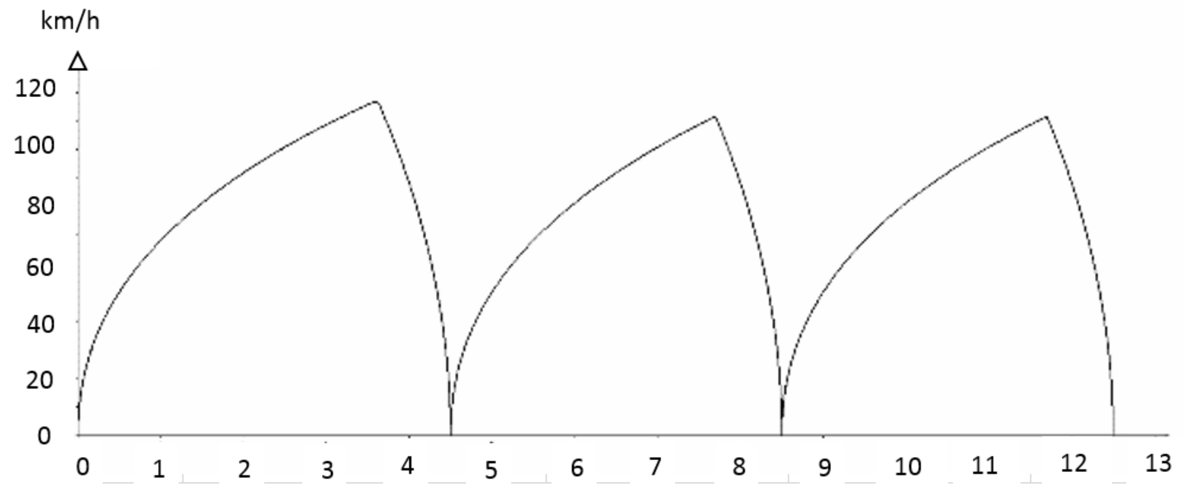


Figure 62: Speed-Distance diagram for the fifth test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course05	STA_1	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course05	STA_2	08:13:48	08:14:13	HH:MM:SS	08:15:13	60	✓	0
course05	STA_3	08:17:37	08:19:11	HH:MM:SS	08:20:11	60	✓	0
course05	STA_4	08:21:25	08:24:09	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 63: third course timetable and delay for fifth test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course06	STA_4	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course06	STA_3	08:13:48	08:14:13	HH:MM:SS	08:15:13	60	✓	0
course06	STA_2	08:17:37	08:19:11	HH:MM:SS	08:20:11	60	✓	0
course06	STA_1	08:21:25	08:24:09	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 64: forth course timetable and delay for fifth test

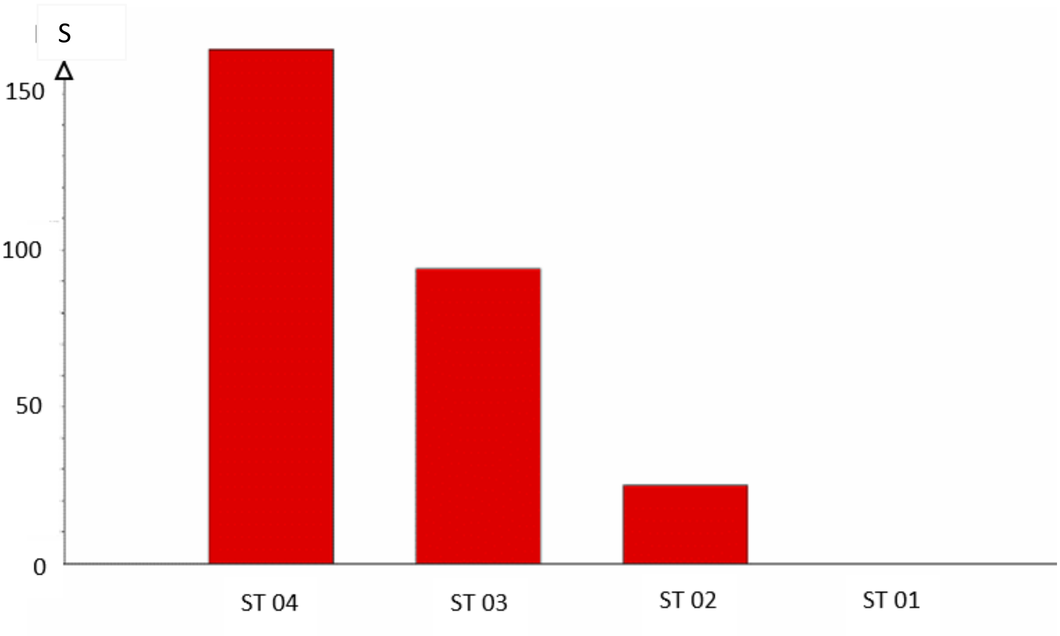


Figure 65: Delay for the fifth test

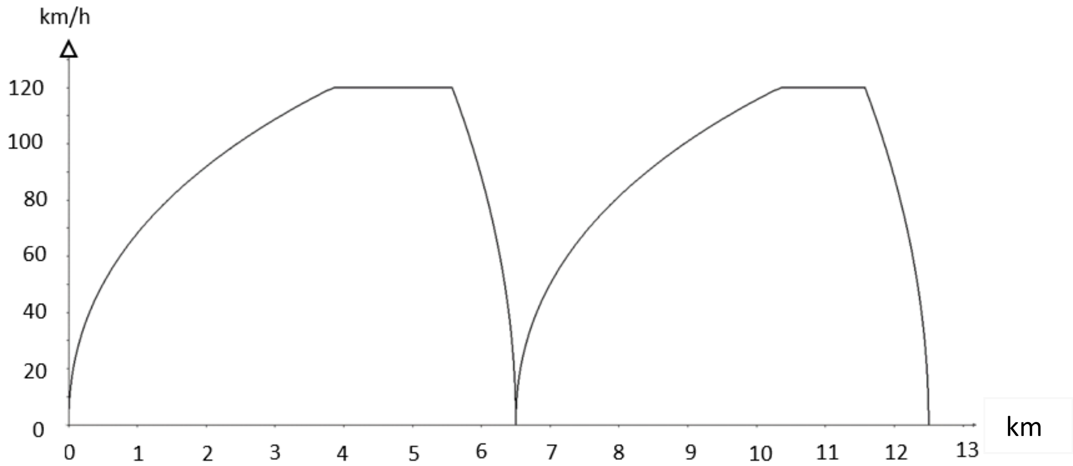


Figure 66: Speed-Distance diagram for the sixth test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course05	STA_1	HH:MM:SS	HH:MM:SS	08:10:00	08:36:47	60	✓	0
course05	STA_2	08:14:48	08:42:01	HH:MM:SS	08:49:16	60	✓	0
course05	STA_3	08:19:37	08:54:15	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 67: fifth course timetable and delay for sixth test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course06	STA_3	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course06	STA_2	08:14:48	08:24:22	HH:MM:SS	08:25:22	60	✓	0
course06	STA_1	08:19:37	08:30:21	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 68: sixth course timetable and delay for sixth test

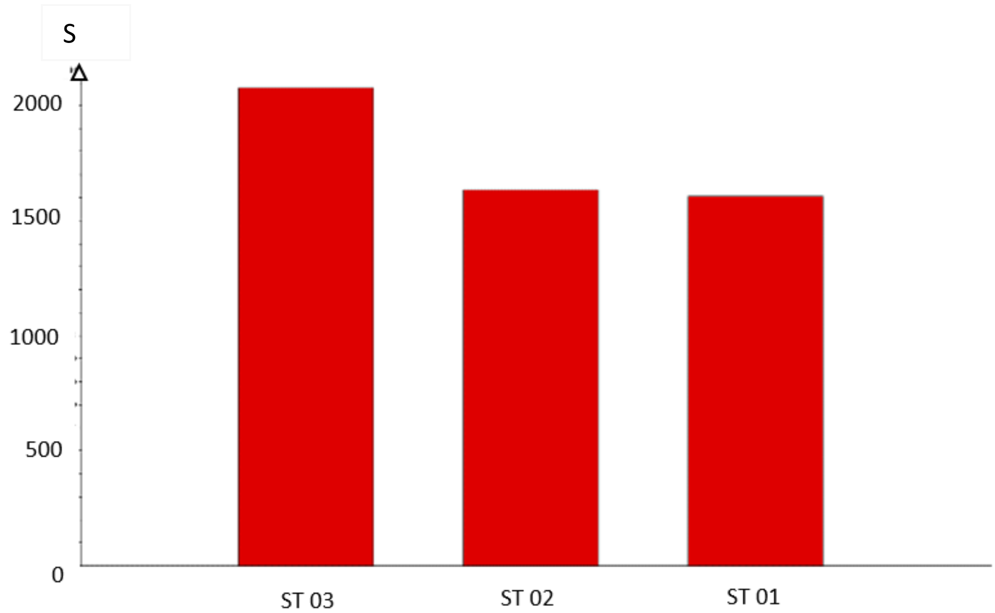


Figure 69: Delay for the sixth test

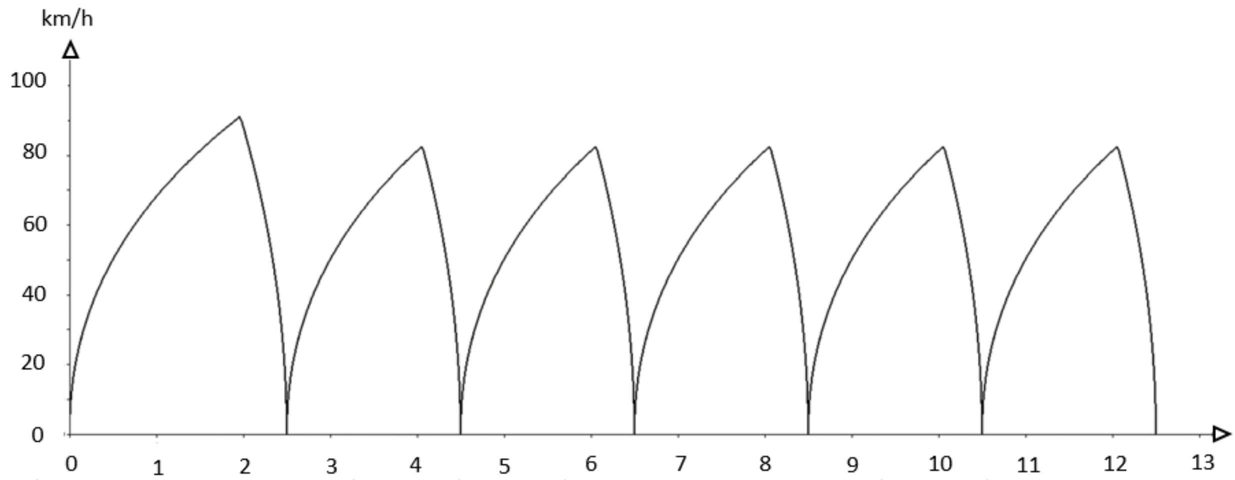


Figure 70: Speed-Distance diagram for the seventh test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course05	STA_1	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course05	STA_2	08:12:48	08:13:05	HH:MM:SS	08:14:05	60	✓	0
course05	STA_3	08:15:37	08:16:49	HH:MM:SS	08:17:49	60	✓	0
course05	STA_4	08:18:25	08:20:33	HH:MM:SS	08:21:33	60	✓	0
course05	STA_5	08:21:14	08:24:17	HH:MM:SS	08:25:17	60	✓	0
course05	STA_6	08:24:03	08:28:01	HH:MM:SS	08:29:01	60	✓	0
course05	STA_7	08:26:51	08:31:45	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 71: fifth course timetable and delay for seventh test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course06	STA_7	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course06	STA_6	08:12:48	08:13:05	HH:MM:SS	08:14:05	60	✓	0
course06	STA_5	08:15:37	08:16:49	HH:MM:SS	08:17:49	60	✓	0
course06	STA_4	08:18:25	08:20:33	HH:MM:SS	08:21:33	60	✓	0
course06	STA_3	08:21:14	08:24:17	HH:MM:SS	08:25:17	60	✓	0
course06	STA_2	08:24:03	08:28:01	HH:MM:SS	08:29:01	60	✓	0
course06	STA_1	08:26:51	08:31:45	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 72: sixth course timetable and delay for seventh test

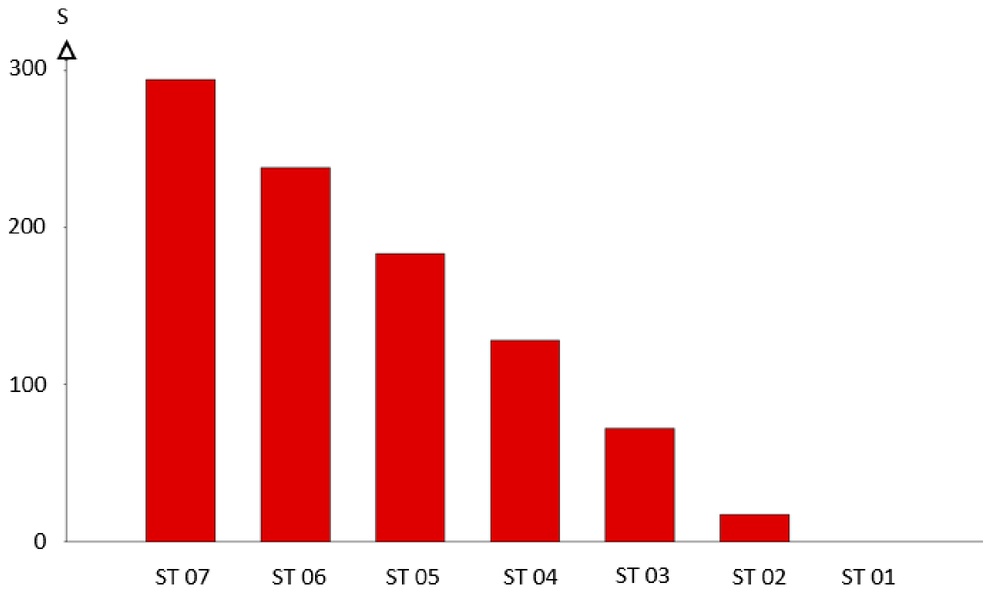


Figure 73: Delay for the seventh test

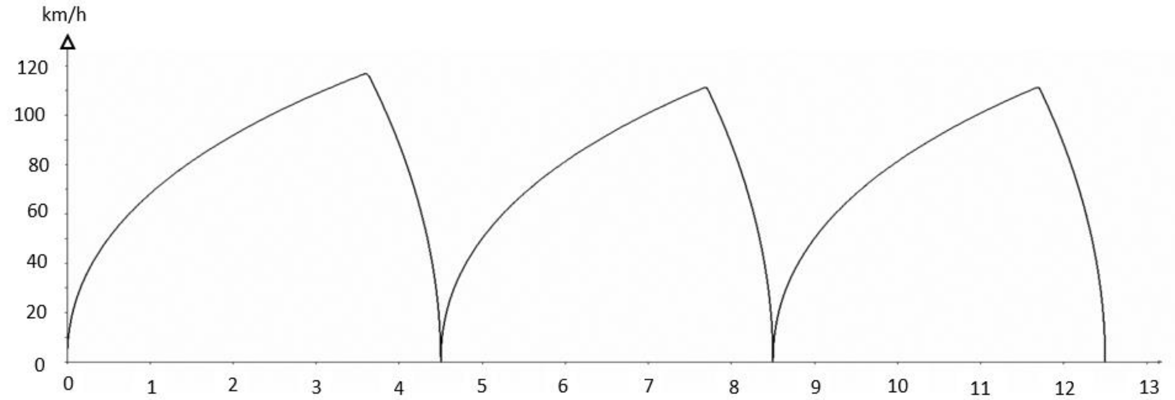


Figure 74: Speed-Distance diagram for the eighth test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course05	STA_1	HH:MM:SS	HH:MM:SS	08:10:00	09:00:46	60	✓	0
course05	STA_2	08:13:34	09:04:59	HH:MM:SS	09:05:59	60	✓	0
course05	STA_3	08:17:09	09:09:57	HH:MM:SS	09:21:09	60	✓	0
course05	STA_4	08:20:44	09:25:07	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 75: fifth course timetable and delay for eighth test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course06	STA_4	HH:MM:SS	HH:MM:SS	08:10:00	08:10:23	60	✓	0
course06	STA_3	08:13:34	08:40:27	HH:MM:SS	08:41:27	60	✓	0
course06	STA_2	08:17:09	08:45:25	HH:MM:SS	08:46:25	60	✓	0
course06	STA_1	08:20:44	08:50:23	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 76: sixth course timetable and delay for eighth test

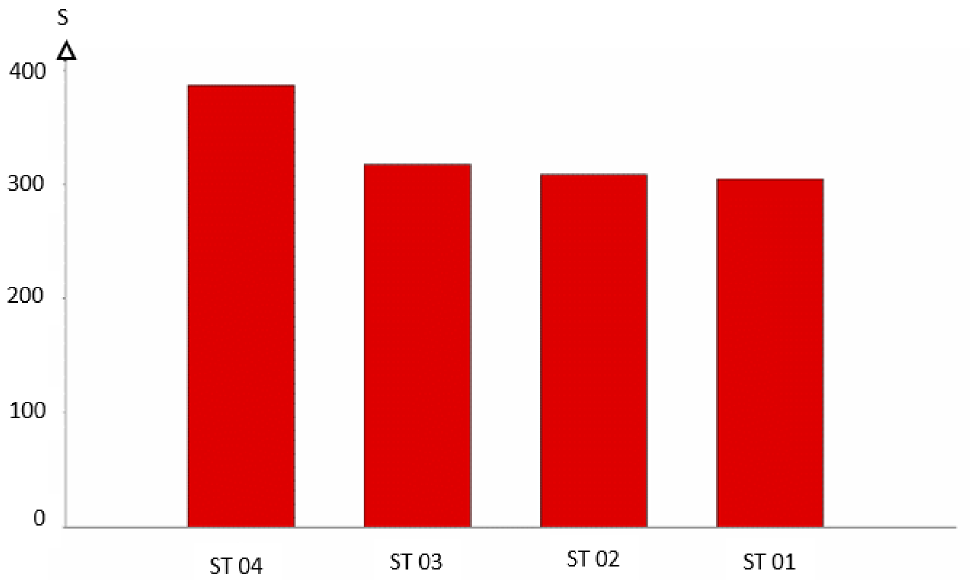


Figure 77: Delay for the eighth test

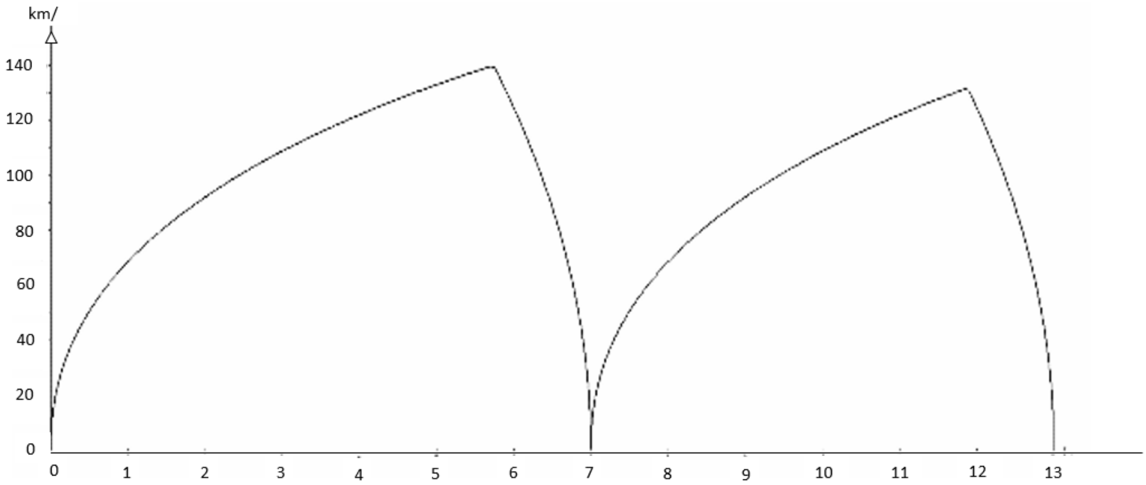
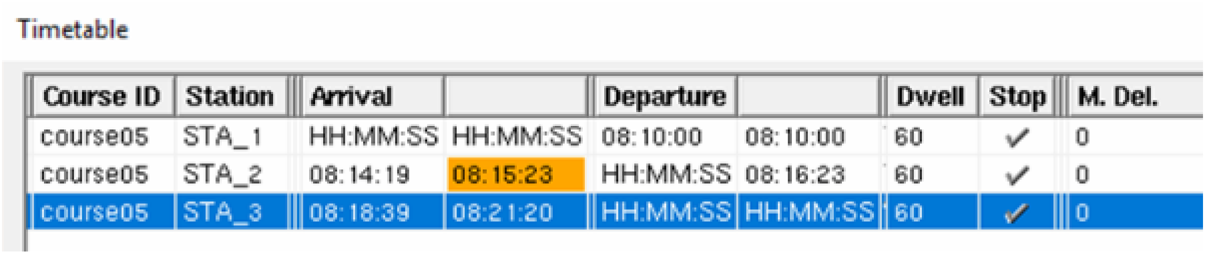


Figure 78: Speed-Distance diagram for the ninth test


Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course05	STA_1	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course05	STA_2	08:14:19	08:15:23	HH:MM:SS	08:16:23	60	✓	0
course05	STA_3	08:18:39	08:21:20	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 79: fifth course timetable and delay for ninth test

Timetable

Course ID	Station	Arrival		Departure		Dwell	Stop	M. Del.
course06	STA_3	HH:MM:SS	HH:MM:SS	08:10:00	08:10:00	60	✓	0
course06	STA_2	08:14:19	08:15:23	HH:MM:SS	08:16:23	60	✓	0
course06	STA_1	08:18:39	08:21:20	HH:MM:SS	HH:MM:SS	60	✓	0

Figure 80: sixth course timetable and delay for ninth test

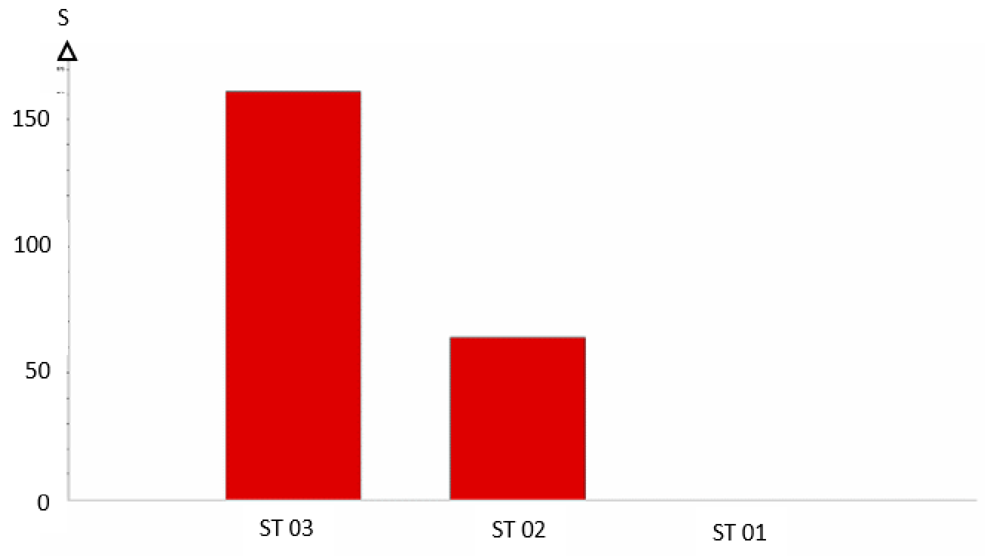


Figure 81: Delay for the ninth test

Chapter 5
Conclusion

Station distance especially in one lane railway should be choosing correctly to allow overtake for the fastest train. But if stationsare so close together, train cannot reach to the maximum speed. All in all, for delays were chosen as a factor for comparing the capacity, following diagrams demonstratedifferent between all of the factors and the results after analysis.

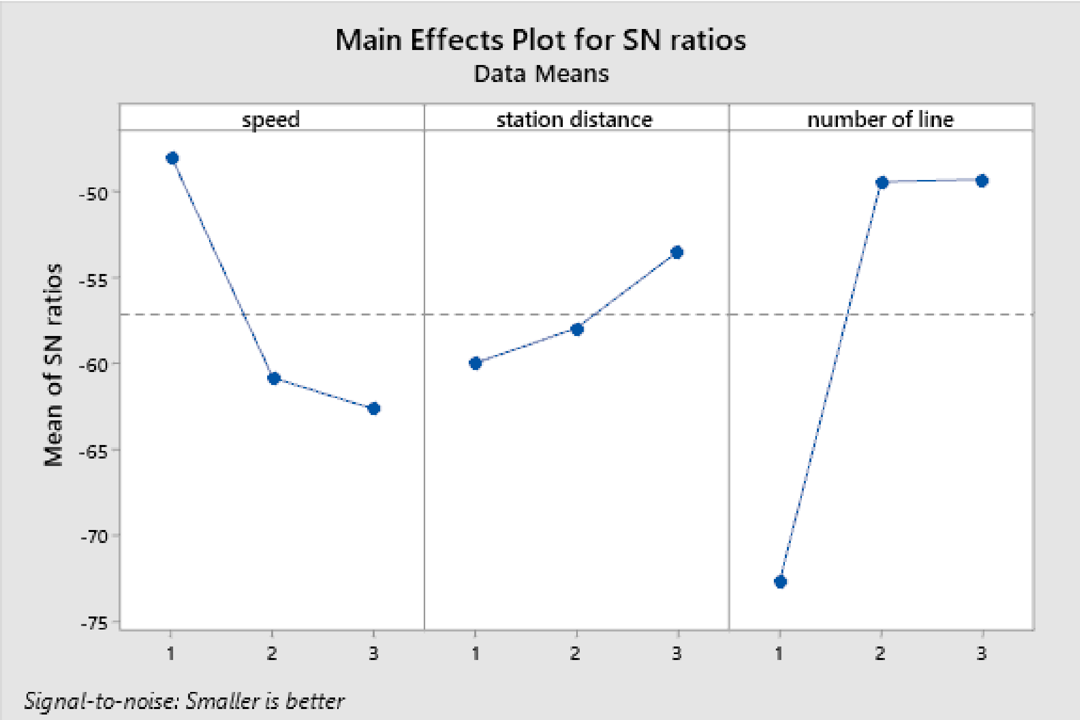


Figure 82: S/N ratio between different factors

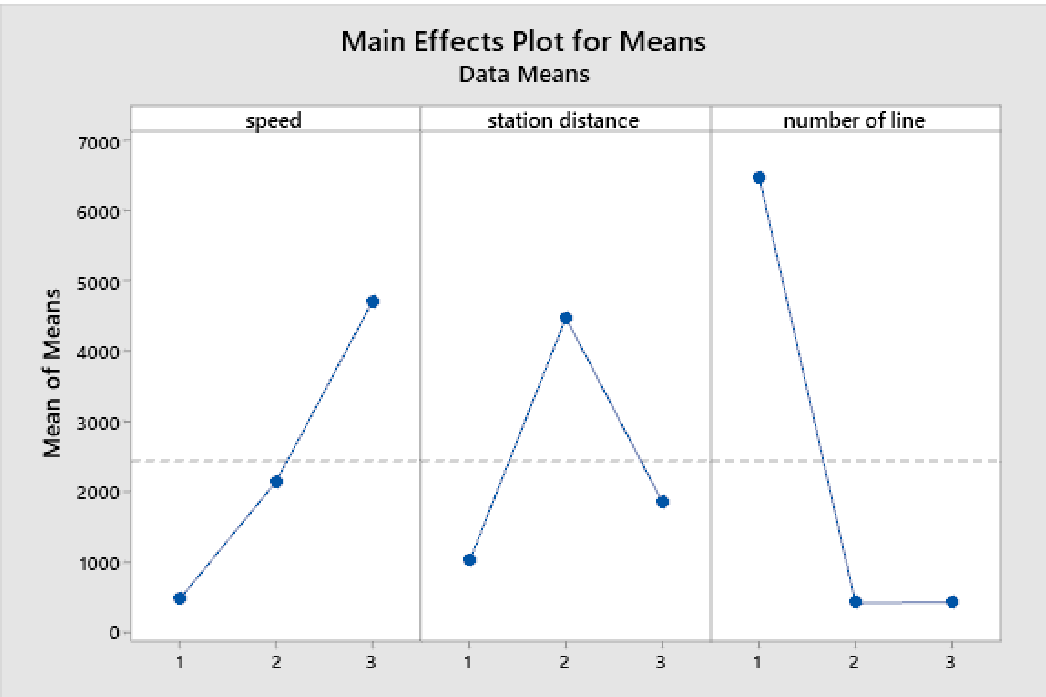


Figure 83: Main effects between factors

Several different methodologies are employed in this thesis in order to analyze capacity. These analyses show us the bigger distance between stations is better because train can reach to the maximum speed, the number of tracks is important and increasing number of tracks from one to two increase capacity and decrease delay so much. But increasing number of tracks from two to four will not have so much effects on analysis. Furthermore, increasing speed in a case with close stations (between 2 and 6 km distance), as we have in this project, not only did not causes increasing capacity but also its lead to increase the delay and uncomfortable situation for the passenger. So speed should be calculated very precise to improving the traffic situation. As we can see in the diagram, the most important factor that influence on the capacity is being two separate track for go and back. It helps significantly for having the best result in capacity. In addition, in second place having more distance between stations helps to reach the maximum speed for the train and increasing the capacity. On the other hand, speed should be designed according to these two factors and cannot be considered as an independent factor.

Finally, these results show us in double track line with intense traffic, more allowance should be allocated to passenger trains and high speed trains, in order to reduce the delay time.

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Appendix

In the picture below, traffic and demand shown in 2015 without any modification in railway system for freight and passenger.

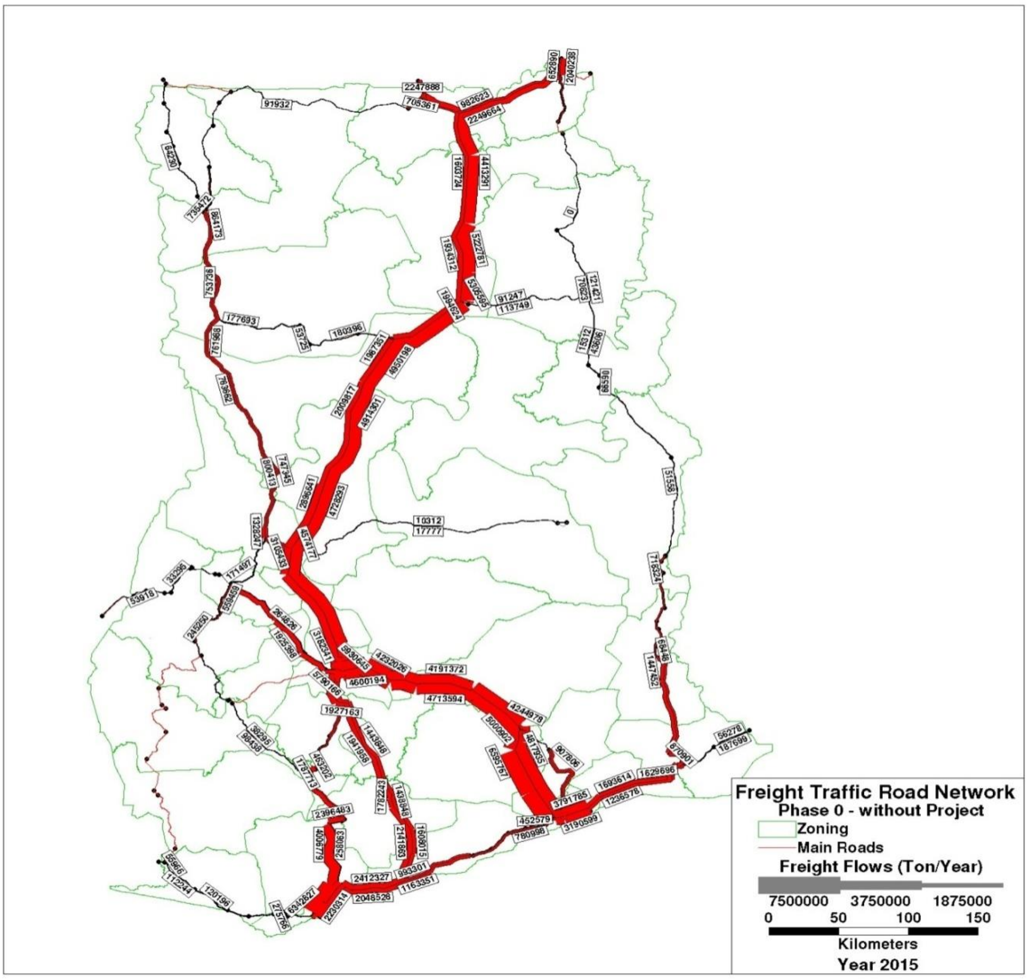

Figure 84: Freight Traffic 2015 – Without Project

Table 15: Freight Traffic Flows – Year 2015

MAIN ROADSCORRIDORS	LENGTH (km)	FREIGHT Average		
		Northbound (Ton)	Southbound (Ton)	Total (Ton)
Western	470	2,181,011	1,288,037	***3,469,049***
Eastern	376	3,666,797	3,431,464	***7,098,261***
Kumasi - Paga	584	2,885,086	3,876,616	***6,761,702***
Ecowas Corridor	411	627,463	871,650	***1,499,113***
Western Expansion	568	752,765	573,882	***1,326,647***
Eastern Expansion	603	236,913	358,124	***595,037***
Transversal 1 – Tamale-Yendi	99	20,030	86,655	***106,685***
Transversal 2 – Fufulsu-Sawla	146	36,482	105,432	***141,914***
Transversal 3 – Techiman-Kwadwokurom	224	17,777	10,312	***28,089***
Transversal 4 – Nyinahin-Kumasi	78	16,980	29,645	***46,625***

Table 16: Passengers/day Traffic Flows – Year 2015

MAIN ROADS CORRIDORS	LENGTH (km)	PASSENGERS Average		
		Northbound (Pass/Day)	Southbound (Pass/Day)	Total (Pass/Day)
Western	470	14,517	14,815	***29,332***
Eastern	376	50,035	50,009	***100,044***
Kumasi Paga	584	11,029	11,033	***22,062***
Ecowas Corridor	411	23,004	23,001	***46,006***
Western Expansion	568	3,988	3,995	***7,983***
Eastern Expansion	603	6,160	6,159	***12,319***
Transversal 1 – Tamale-Yendi	99	369	367	***735***
Transversal 2 – Fufulsu-Sawla	146	322	326	***648***
Transversal 3 – Techiman-Kwadwokurom	224	233	233	***465***
Transversal 4 – Nyinahin-Kumasi	78	1,102	1,203	***2,306***

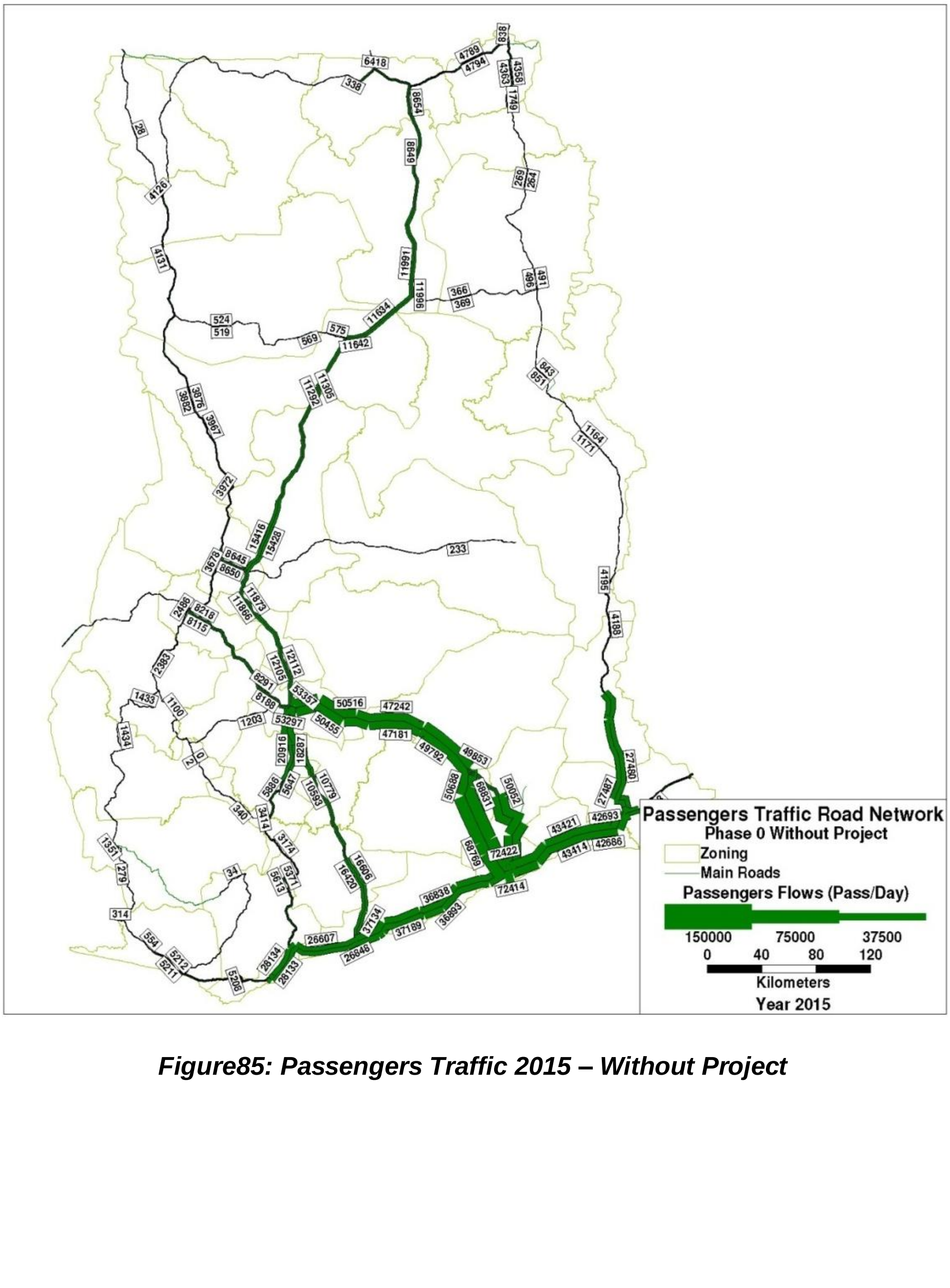

Figure85: Passengers Traffic 2015 – Without Project

In the picture below, traffic and demand shown in 2015 without construction of first phase of the western line for freight and passenger.

Table 17: Freight – Year 2015

CORRIDORS	ROAD			RAILWAY		
	Northbound (Ton)	Southbound (Ton)	Total Average (Ton)	Northbound (Ton)	Southbound (Ton)	Total Average (Ton)
WESTERN	1,474,657	903,439	***2,378,096***	487,582	1,518,666	2,006,248
EASTERN	3,626,423	3,400,143	***7,026,567***	0	0	0
KUMASI PAGA	2,885,086	3,880,637	***6,765,723***	0	0	0
ECOWAS CORRIDOR	642,838	678,554	***1,321,392***	0	0	0
WESTERN EXPANSION	735,376	560,281	***1,295,657***	0	0	0
EASTERN EXPANSION	236,913	358,124	***595,037***	0	0	0
TRANSVERSAL 1 – TAMALE-YENDI	20,030	86,655	***106,685***	0	0	0
TRANSVERSAL 2 – FUFULSU-SAWLA	36,482	105,432	***141,914***	0	0	0
TRANSVERSAL 3 – TECHIMAN-KWADWOKUROM	17,777	10,312	***28,089***	0	0	0
TRANSVERSAL 4 – NYINAHIN-KUMASI	29	775	***804***	0	0	0

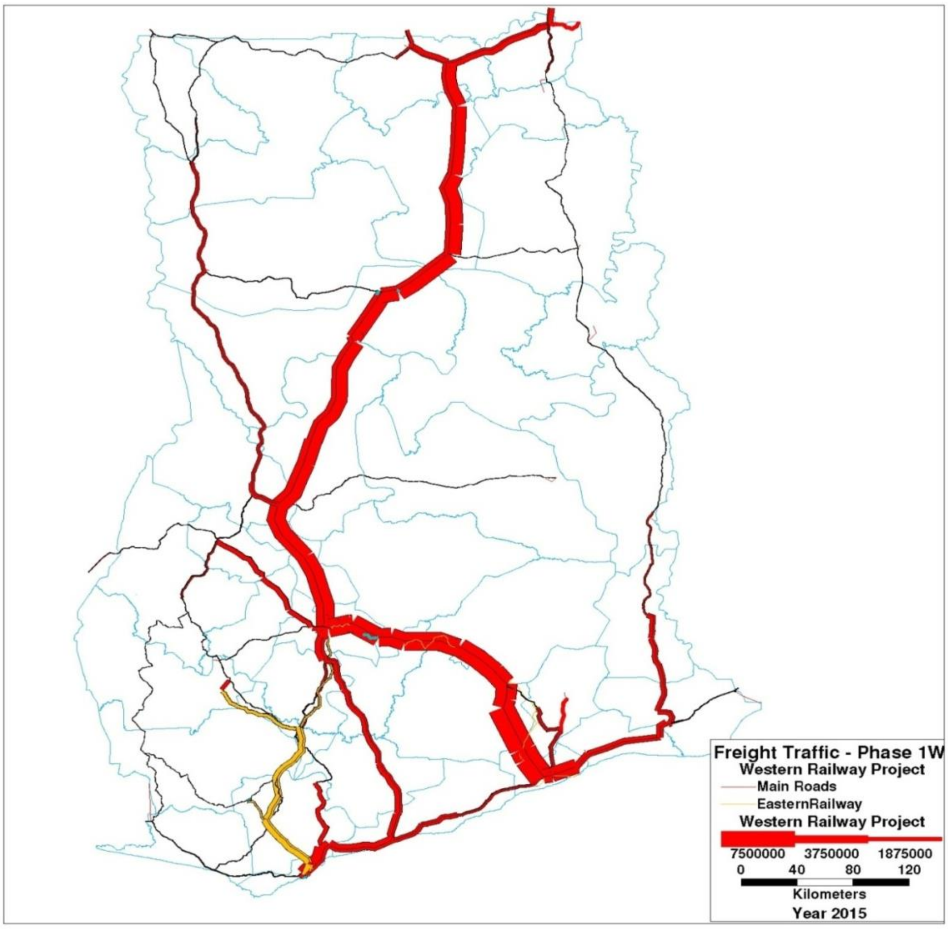

Figure86: Freight Traffic 2015 – Phase 1W Western Railway Project

Table 18: Passengers – Year 2015

CORRIDORS	ROAD			RAILWAY		
	Northbound (Pass/Day)	Southbound (Pass/Day)	Total Average (Pass/Day)	Northbound (Pass/Day)	Southbound (Pass/Day)	ToT. Average (Pass/Day)
WESTERN	12,840	13,176	26,016	2,960	3,006	5,967
EASTERN	49,981	49,945	99,926	0	0	0
KUMASI PAGA	11,032	11,037	22,069	0	0	0
ECOWAS CORRIDOR	22,952	22,952	45,904	0	0	0
WESTERN EXPANSION	3,952	3,959	7,911	0	0	0
EASTERN EXPANSION	6,160	6,159	12,319	0	0	0
TRANSVERSAL 1 – TAMALE-YENDI	369	367	735	0	0	0
TRANSVERSAL 2 – FUFULSU-SAWLA	322	326	648	0	0	0
TRANSVERSAL 3 – TECHIMAN-KWADWOKUROM	233	233	465	0	0	0
TRANSVERSAL 4 – NYINAHIN-KUMASI	0	103	103	0	0	0

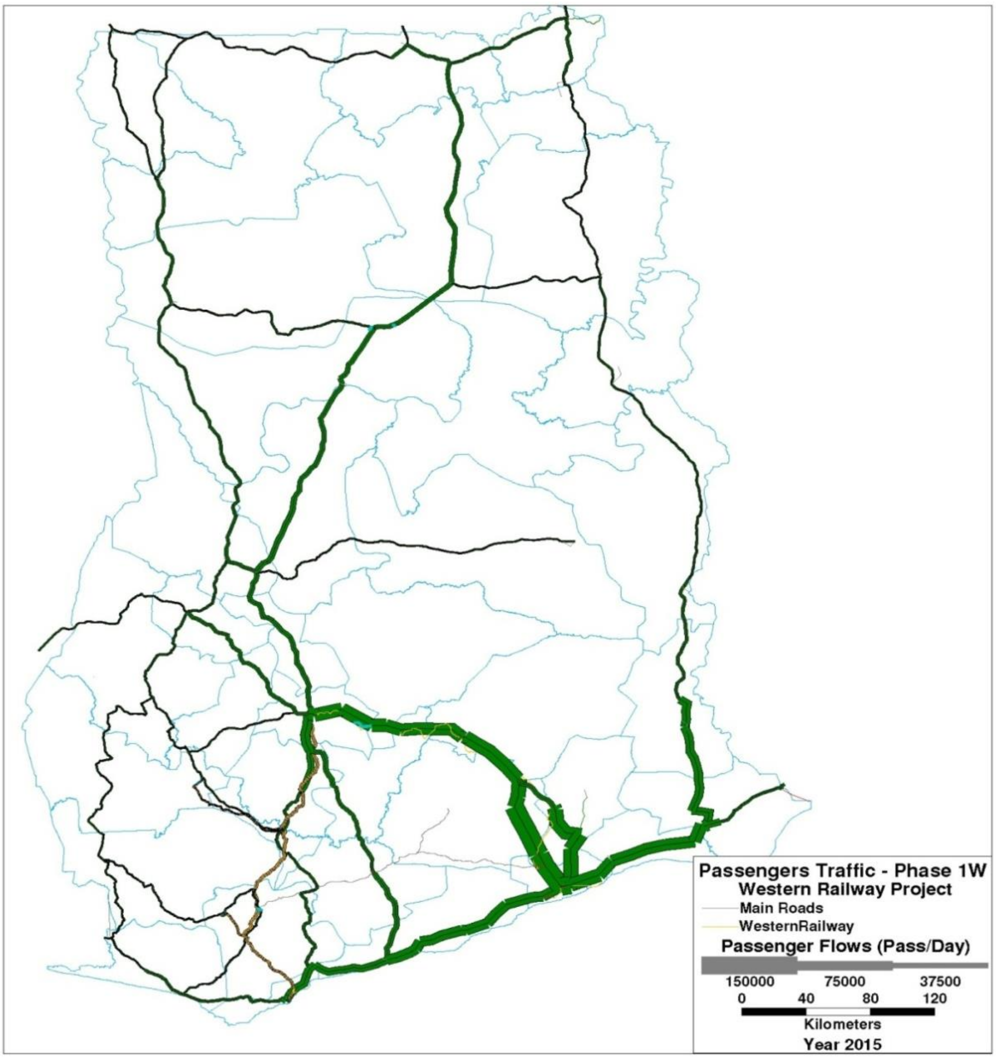

Figure 87: Passengers Traffic 2015 – Phase 1W Western Railway Project

In the picture below, traffic and demand shown in 2030 without any modification in railway system for freight and passenger.

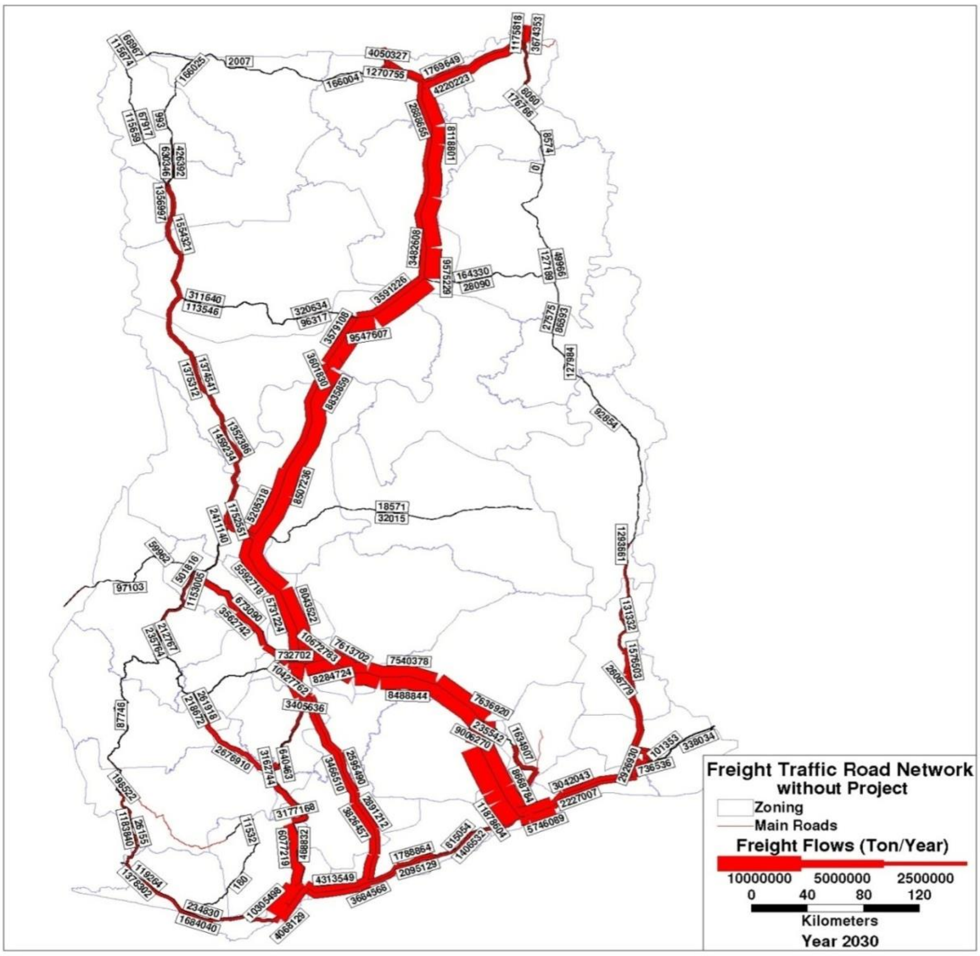

Figure 88: Freight Traffic 2030 – Without Project

Table 19: Freight – Year 2030

CORRIDORS	ROAD			RAILWAY		
	Northbound (Ton)	Southbound (Ton)	Total Average (Ton)	Northbound (Ton)	Southbound (Ton)	Total Average (Ton)
Western	3,857,216	2,274,846	6,132,063	0	0	0
Eastern	6,614,930	6,185,644	12,800,574	0	0	0
Kumasi Paga	5,193,730	6,944,243	12,137,973	0	0	0
Ecowas Corridor	1,122,645	1,561,965	2,684,610	0	0	0
Western Expansion	1,342,651	1,042,265	2,384,916	0	0	0
Eastern Expansion	430,833	648,928	1,079,760	0	0	0
Transversal 1 – Tamale-Yendi	36,342	156,078	192,420	0	0	0
Transversal 2 – Fufulsu-Sawla	65,776	189,996	255,772	0	0	0
Transversal 3 – Techiman-Kwadwokurom	32,015	18,571	50,586	0	0	0
Transversal 4 – Nyinahin-Kumasi	71,898	248,918	320,816	0	0	0

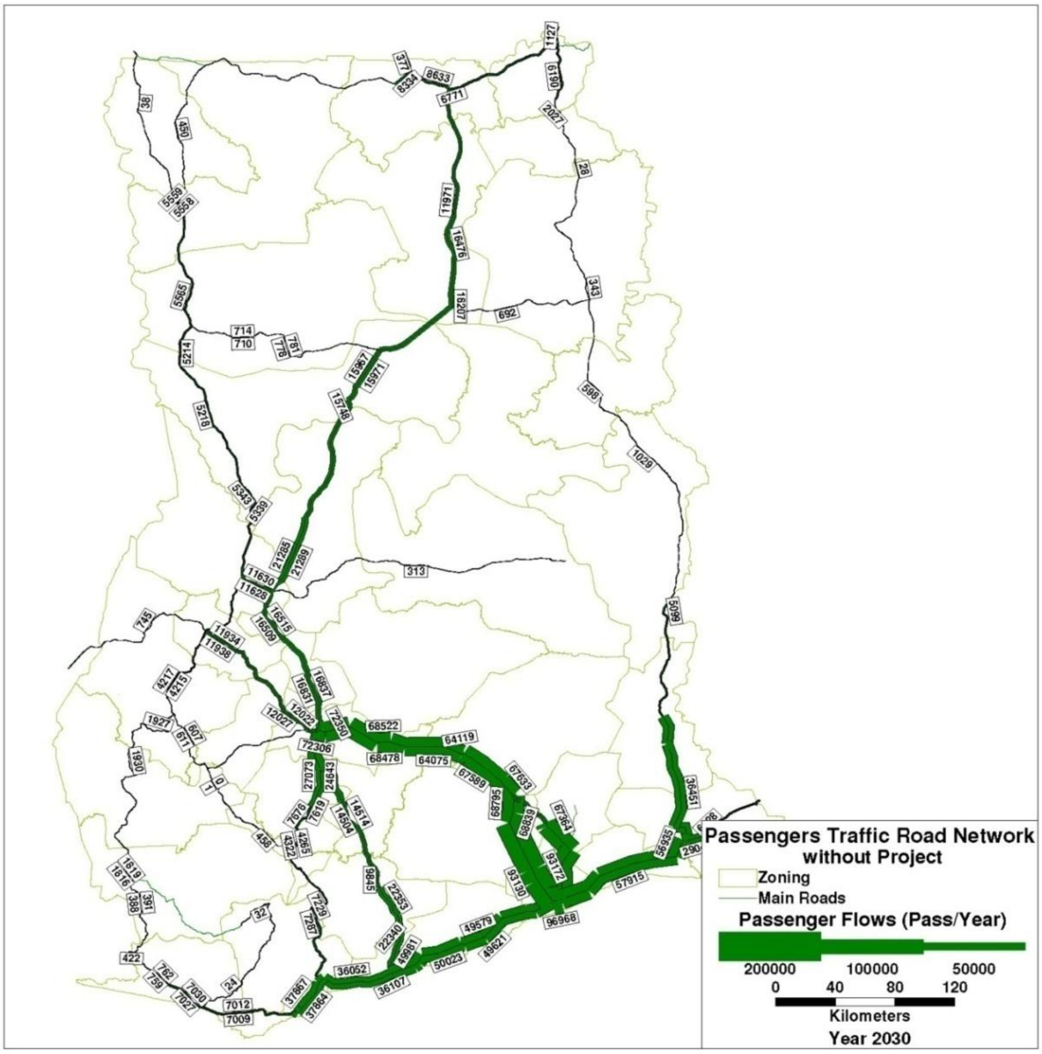

Figure 89: Passenger Traffic 2030 – Without Project

Table 20: Passengers/day – Year 2030

CORRIDORS	ROAD			RAILWAY		
	Northbound (Pass/Day)	Southbound (Pass/Day)	Total Average (Pass/Day)	Northbound (Pass/Day)	Southbound (Pass/Day)	Total Average (Pass/Day)
Western	19,596	19,876	39,472	0	0	0
Eastern	67,669	67,631	135,300	0	0	0
Kumasi Paga	15,285	15,287	30,573	0	0	0
Ecowas Corridor	30,848	30,845	61,694	0	0	0
Western Expansion	5,552	5,550	11,102	0	0	0
Eastern Expansion	7,803	7,803	15,606	0	0	0
Transversal 1 – Tamale-Yedi	692	692	1,384	0	0	0
Transversal 2 – Fufulsu-Sawla	441	443	884	0	0	0
Transversal 3 – Techiman-Kwadwokurom	313	313	626	0	0	0
Transversal 4 – Nyinahin-Kumasi	607	611	1,218	0	0	0

In the picture below, traffic and demand shown in 2047 without any modification in railway system for freight and passenger.

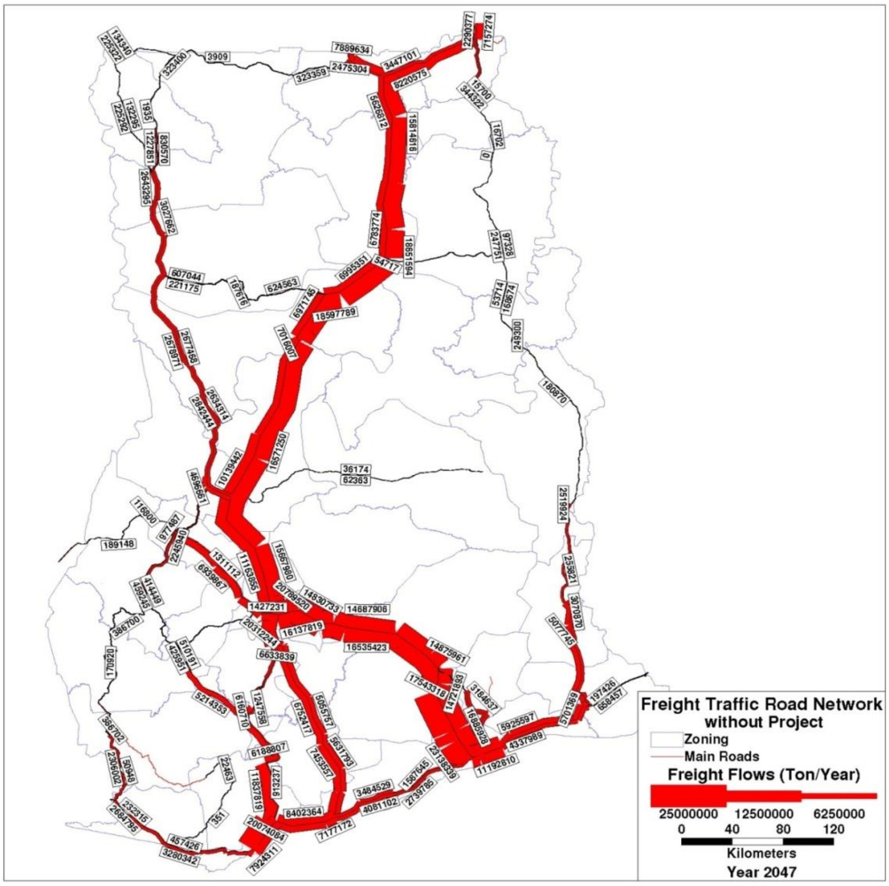

Figure 90: Freight Traffic 2047 – Without Project

Table 21: Freight – Year 2047

CORRIDORS	ROAD			RAILWAY		
	Northbound (Ton)	Southbound (Ton)	Total Average (Ton)	Northbound (Ton)	Southbound (Ton)	Total Average (Ton)
WESTERN	7,513,474	4,431,174	11,944,648	0	0	0
EASTERN	12,885,225	12,049,019	24,934,244	0	0	0
KUMASI PAGA	10,116,869	13,526,695	23,643,564	0	0	0
ECOWAS CORRIDOR	2,186,801	3,042,552	5,229,354	0	0	0
WESTERN EXPANSION	2,615,351	2,030,228	4,645,578	0	0	0
EASTERN EXPANSION	839,219	1,264,047	2,103,265	0	0	0
TRANSVERSAL 1 – TAMALE-YENDI	70,790	304,026	374,815	0	0	0
TRANSVERSAL 2 – FUFULSU-SAWLA	128,124	370,093	498,217	0	0	0
TRANSVERSAL 3 – TECHIMAN-KWADWOKUROM	62,363	36,174	98,537	0	0	0
TRANSVERSAL 4 – NYINAHIN-KUMASI	140,051	484,867	624,918	0	0	0

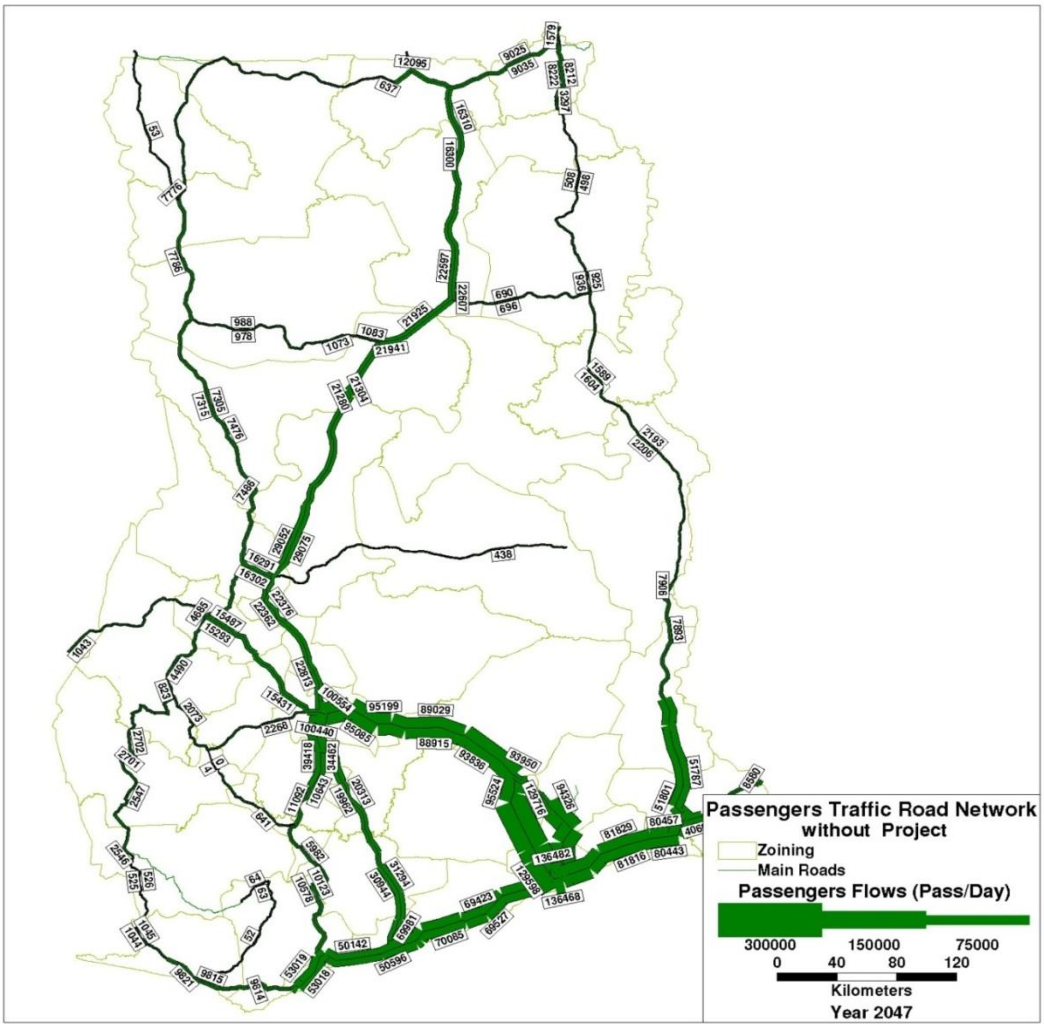

Figure91: Passenger Traffic 2047 – Without Project

Table 22: Passengers – Year 2047

CORRIDORS	ROAD			RAILWAY		
	Northbound (Pass/Day)	Southbound (Pass/Day)	Total Average (Pass/Day)	Northbound (Pass/Day)	Southbound (Pass/Day)	Total Average (Pass/Day)
WESTERN	27,358	27,920	55,278	0	0	0
EASTERN	94,292	94,245	188,537	0	0	0
KUMASI PAGA	20,785	20,793	41,578	0	0	0
ECOWAS CORRIDOR	43,352	43,347	86,699	0	0	0
WESTERN EXPANSION	7,516	7,528	15,044	0	0	0
EASTERN EXPANSION	11,609	11,608	23,216	0	0	0
TRANSVERSAL 1 – TAMALE-YENDI	696	690	1,386	0	0	0
TRANSVERSAL 2 – FUFULSU-SAWLA	607	614	1,221	0	0	0
TRANSVERSAL 3 – TECHIMAN-KWADWOKUROM	438	438	877	0	0	0
TRANSVERSAL 4 – NYINAHIN-KUMASI	2,077	2,268	4,345	0	0	0

In the picture below, traffic and demand shown in 2041 after constructing all 6 phase that predicted in master plan for freight and passenger.

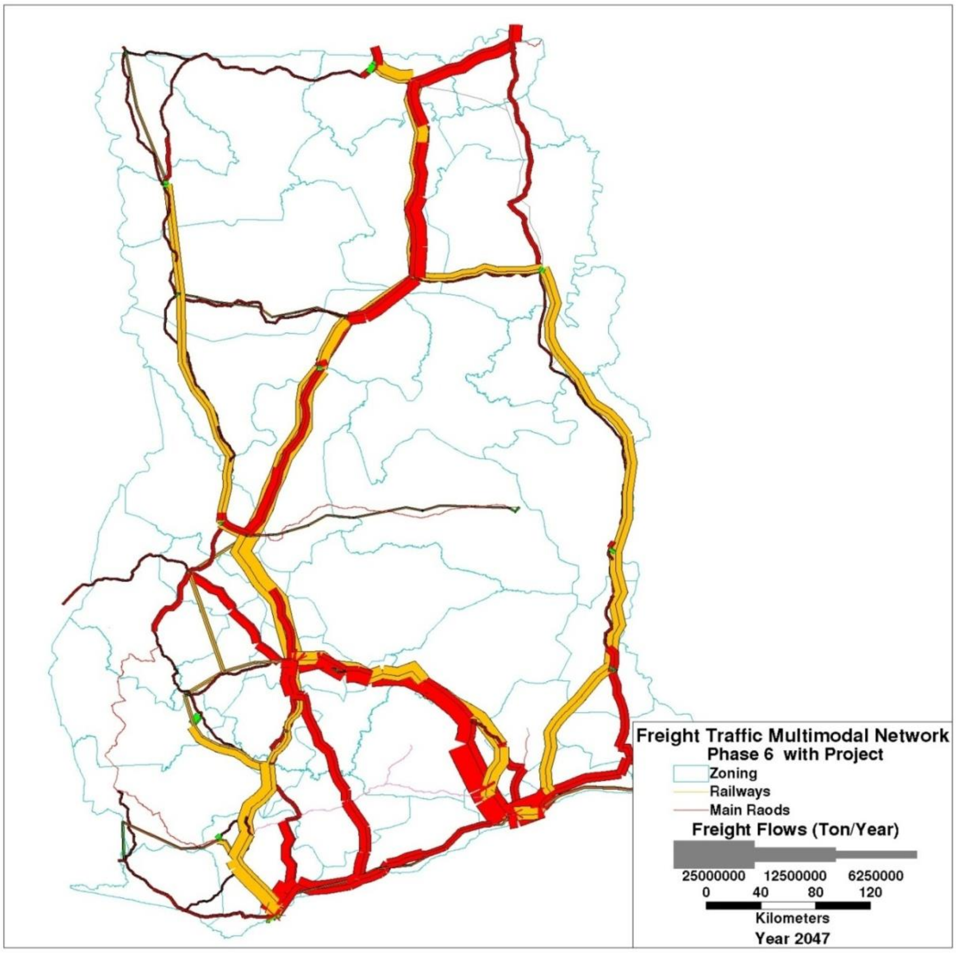

Figure 92: Multimodal Freight Traffic 2047 – Phase 6

Table 23: Freight – Year 2047

CORRIDORS	ROAD			RAILWAY		
	Northbound (Ton)	Southbound (Ton)	Total Average (Ton)	Northbound (Ton)	Southbound (Ton)	Total Average (Ton)
Western	4,534,362	2,838,134	7,372,496	2,097,846	5,788,211	7,886,056
Eastern	7,232,601	5,997,788	13,230,388	5,217,478	5,753,266	10,970,744
Kumasi Paga	3,883,265	3,671,459	7,554,724	9,420,726	3,983,287	13,404,013
Ecowas Corridor	1,893,105	1,909,757	3,802,861	432,878	117,743	550,621
Western Expansion	1,022,605	586,811	1,609,417	1,802,465	1,852,497	3,654,962
Eastern Expansion	909,420	989,000	1,898,420	2,466,754	3,079,279	5,546,033
Transversal 1 – Tamale-Yendi	516,904	101,009	617,913	1,834,546	3,899,930	5,734,476
Transversal 2 – Fufulsu-Sawla	112,916	245,984	358,899	72,576	20,677	93,253
Transversal 3 – Techiman-Kwadwokurom	0	0	0	62,363	36,174	98,537
Transversal 4 – Nyinahin-Kumasi	80,387	372,746	453,133	539,234	418,460	957,694

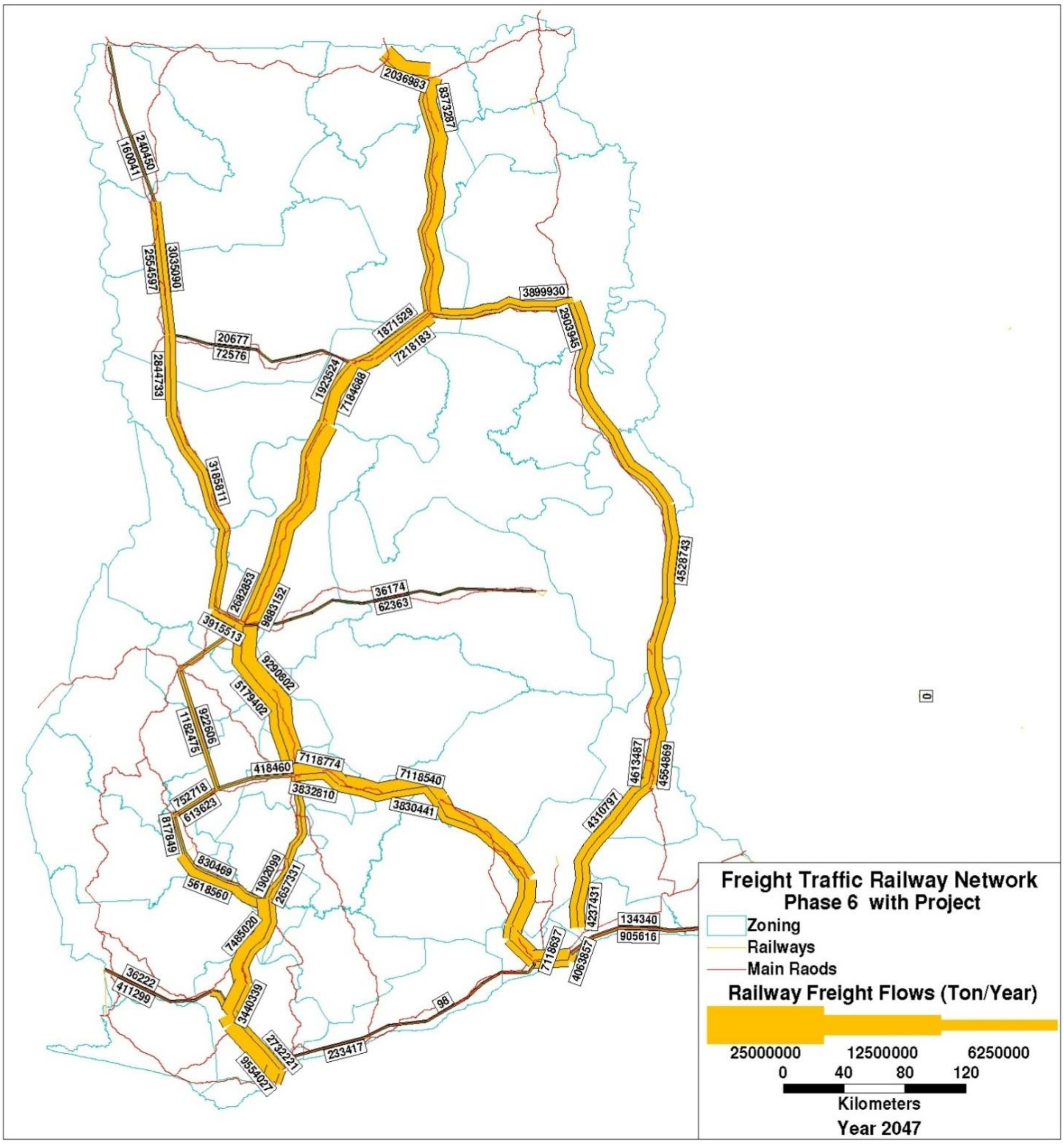

Figure 93: Railway Freight Traffic 2047 – Phase 6

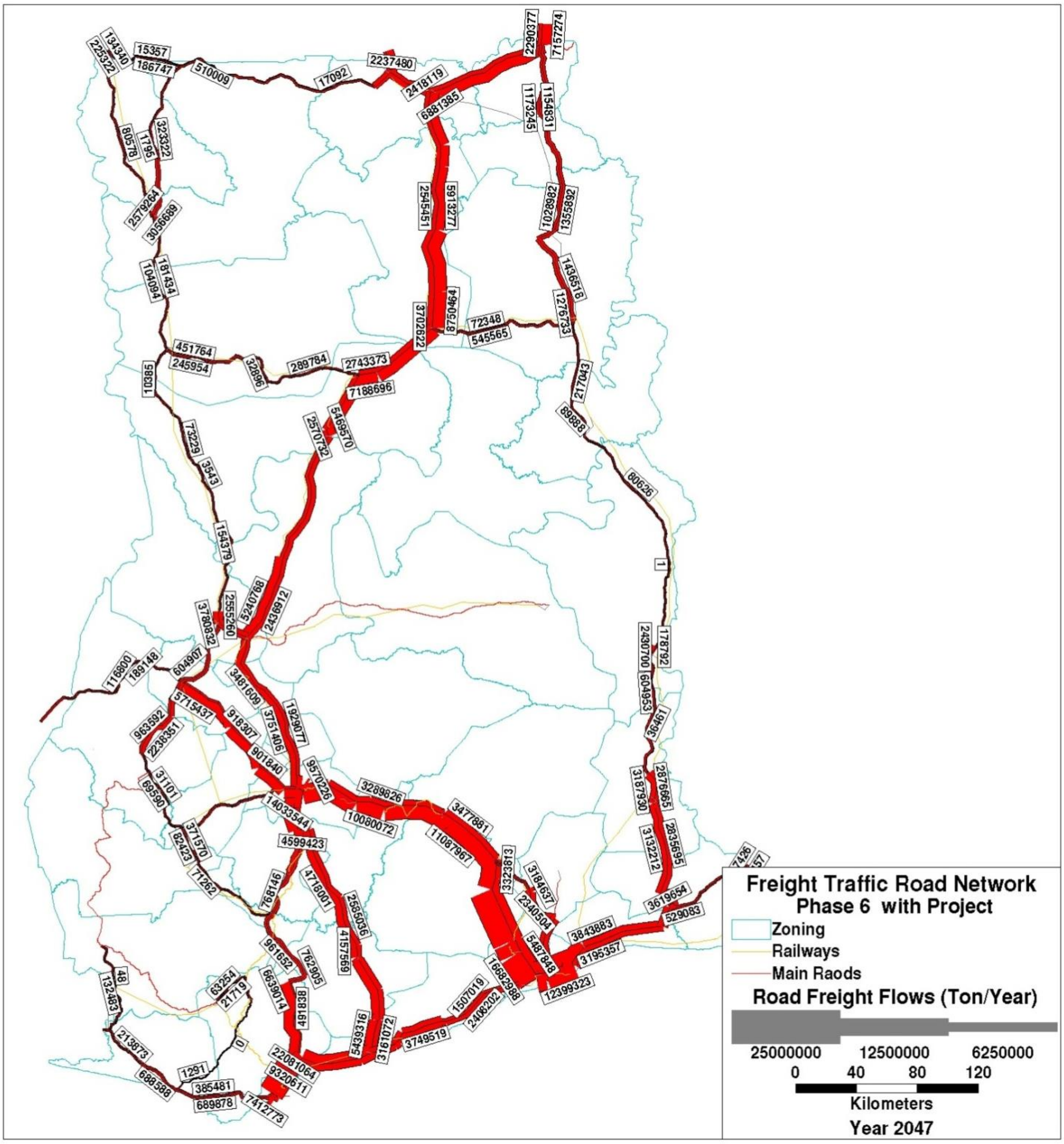

Figure 94: Road Freight Traffic 2047 – Phase 6

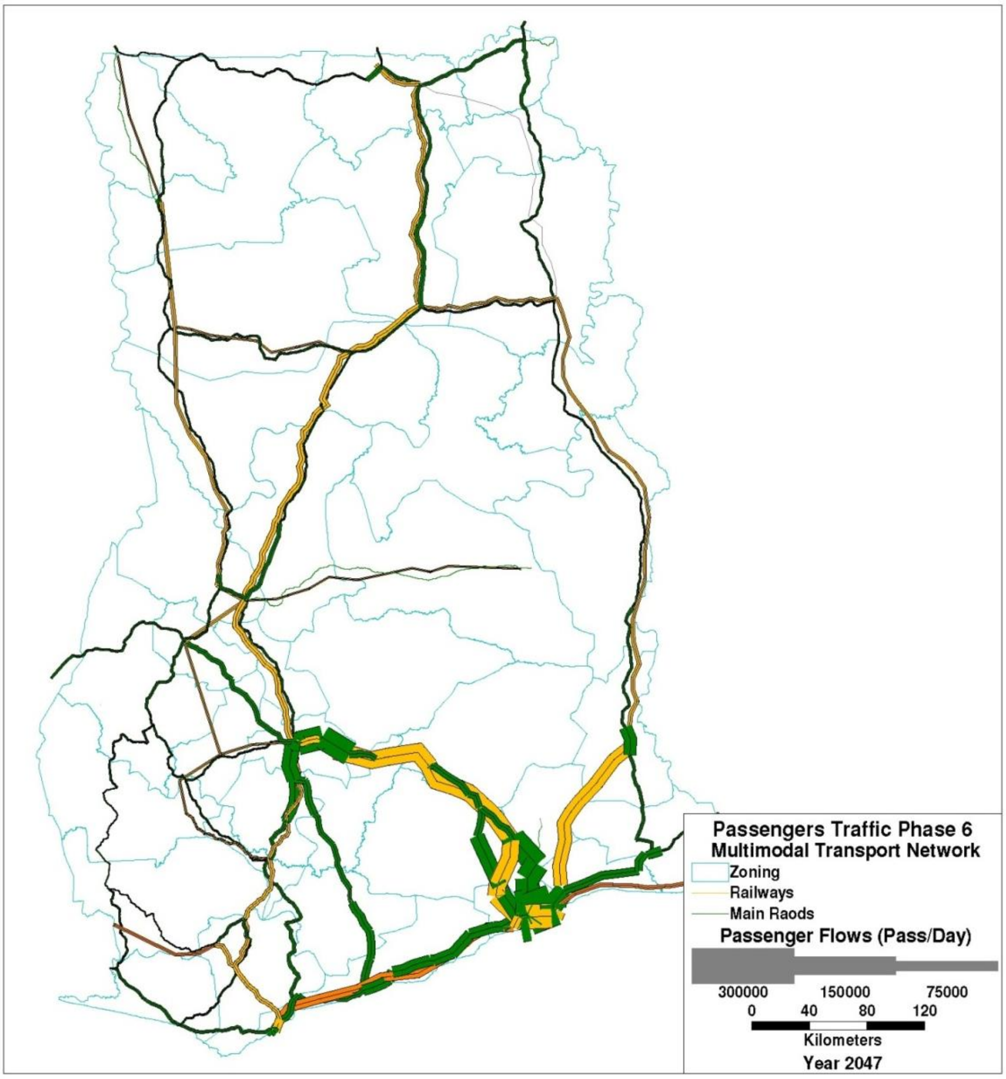

Figure 95: Multimodal Passengers Traffic 2047 – Phase 6

Table 24: Passengers – Year 2047

CORRIDORS	ROAD			RAILWAY		
	Northbound (Pass/Day)	Southbound (Pass/Day)	Total Average (Pass/Day)	Northbound (Pass/Day)	Southbound (Pass/Day)	Total Average (Pass/Day)
WESTERN	17,897	18,606	36,502	7,955	7,977	15,932
EASTERN	61,804	61,342	123,146	64,543	66,088	130,631
KUMASI PAGA	3,822	3,805	7,627	18,115	18,127	36,242
ECOWAS CORRIDOR	21,586	21,804	43,390	18,596	19,790	38,386
WESTERN EXPANSION	2,656	2,670	5,326	4,991	4,933	9,924
EASTERN EXPANSION	3,926	3,926	7,852	11,984	11,987	23,972
TRANSVERSAL 1 – TAMALE-YENDI	33	37	70	6,045	6,050	12,095
TRANSVERSAL 2 – FUFULSU-SAWLA	457	458	916	961	933	1,894
TRANSVERSAL 3 – TECHIMAN-KWADWOKUROM	0	0	0	438	438	877
TRANSVERSAL 4 – NYINAHIN-KUMASI	1	160	161	2,198	2,173	4,371

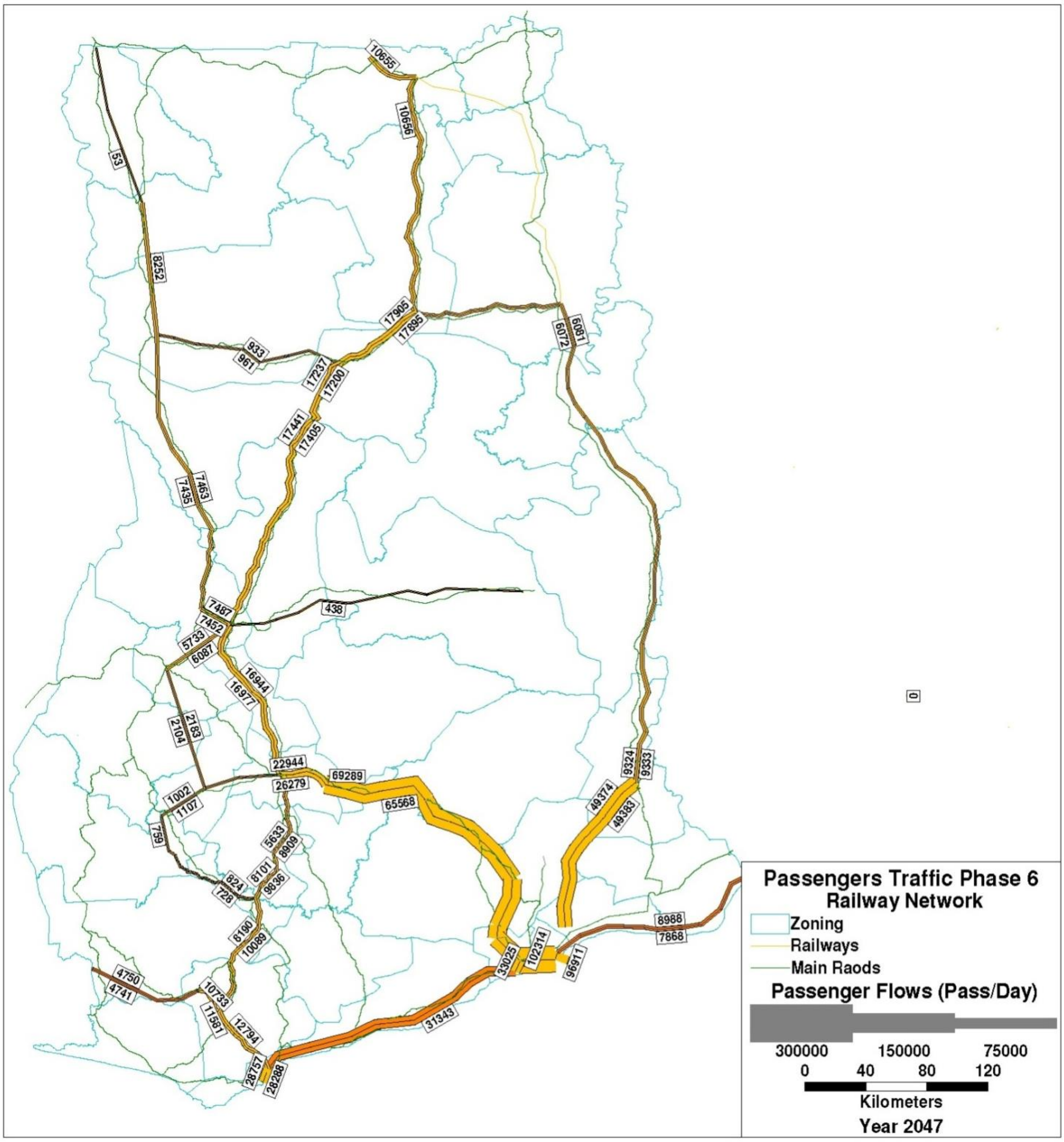

Figure 96: Railway Passengers Traffic 2047 – Phase 6

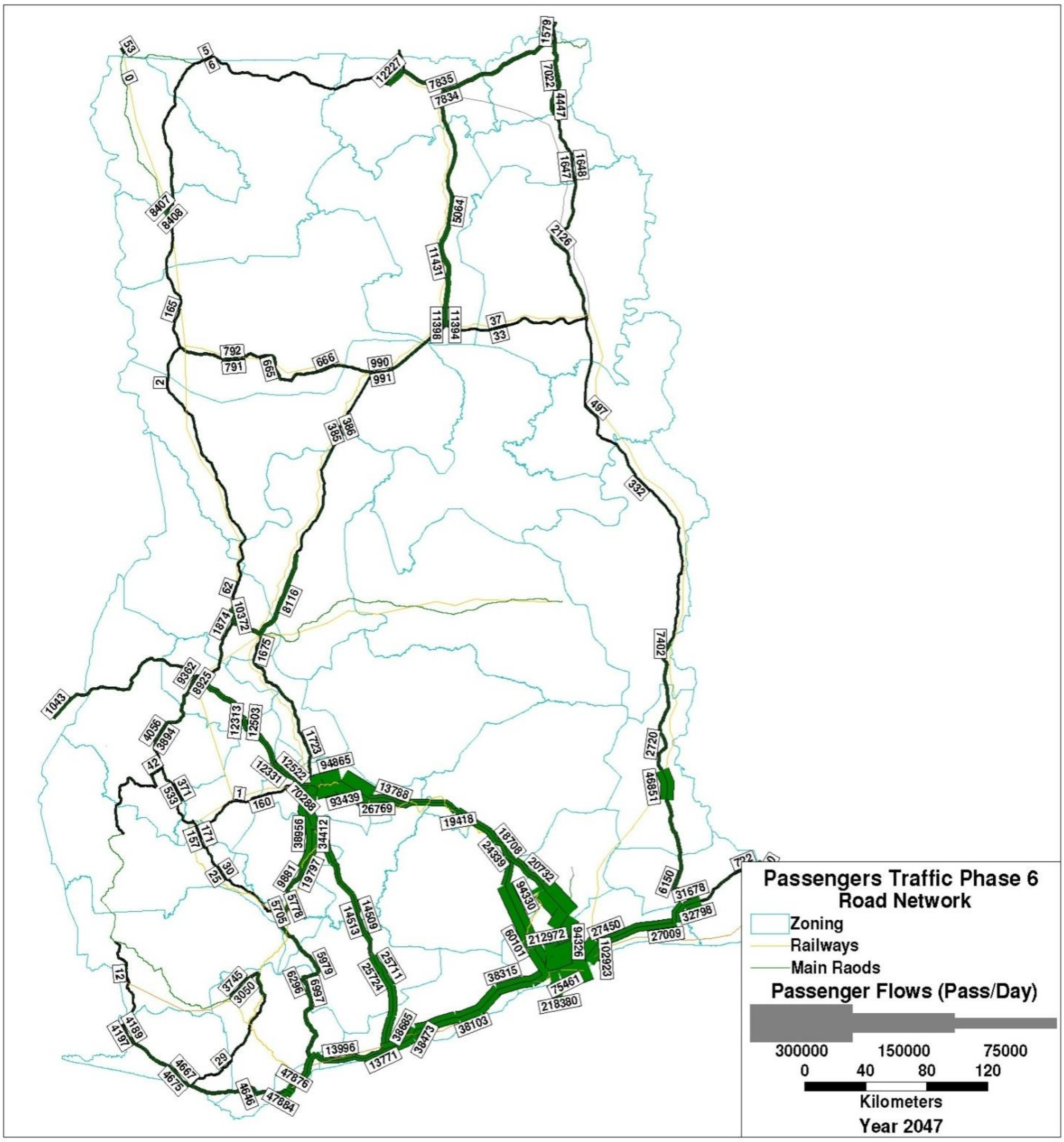

Figure 97: Road Passengers Traffic 2047 – Phase 6