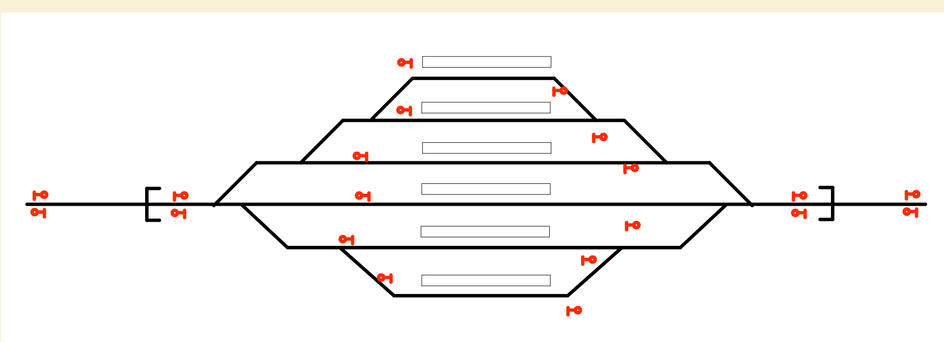
Capacity estimation of new single track stations

SOLOMON KINFE



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Capacity estimation of new single track stations

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Abstract

The capacity output of single track stations is limited due to the fact that trains' occupation in a track section blocks other trains which should run in opposite direction and thus, making the arrival frequency of trains low and elongating dwell time at station. The capacity constraint becomes more intense as mix of traffic is introduced in the operation which gives rise to great dependency and interaction of trains to one another. Thus, determination of the factors for maximizing output capacity of a station is vital to study. With the help of computer tool majority of the real life operation can be modeled in many alternatives. Different infrastructural and operational scenarios are setup in simulation program, and the operational parameters from simulation process are used to estimate analytically the capacity of station.

This paper studies the trend of capacity as function of variable parameters from operational and infrastructural dimensions such as block sections, station track size etc.; and figures out which parameters do actually affect most the routing of trains in single track station under different circumstantial assumptions.

Increasing trends of capacity is seen from different experiments undertaken to maximize capacity of single track station. However, under considered circumstances of operation and infrastructural setups, the increment in capacity per hour is found to be insignificant. The contribution of signaling system in maximizing capacity is also limited. The mixture of traffic over the single track line is one cause for less usage of available track capacity. Either homogenizing the service for high frequent trains i.e. commuter trains or doubling the track lines for all services would increase the performance of station.

Keywords: Capacity; Simulation; Single track station; Timetable; Dwell time; Arrival delay; Perturbation; Deadlock

1. INTRODUCTION

1.1 Background

The complexity of railway operation, technical constraints and demand of passengers results in quite large number of possibilities of alternations. This enforces us to consider several alternatives in studying and planning of railway infrastructures and operation.

Performance of railway stations depends greatly on its infrastructural design and operational parameters. Capacity for single track stations requires more attention in selection of these parameters because it is always preferred to utilize single tracks and stations with optimum capacity instead of building expensive double tracks. The bottle necks in utilizing the railway capacity arises at station areas due to the fact that many switches and side tracks exist. In single track stations, crossing trains have to wait at platform for meeting trains before departure. The presence of delays in arrival of trains will also impact trains at station.

Different design of time table, with different mix of trains can produce variable capacity output and accordingly may require different infrastructural investments.

In this study simulation and analytical methods are combined for estimation of capacity. The output statistical data from train simulation are used in analytical equation to estimate the number of train routing through the station per time unit. Cyclic timetables are simulated for some hours of the day to represent daily operation with all possible train interactions and with no irregular gap between trains.

The simulation and analytical methods used in this paper may be used in different ways. They may be used by traffic planners, infrastructure managers or operators in testing the reliability of proposed station layout and timetable schedules before adopting them. They may also be used in exploring how scheduled timetable would be altered by change of proposals such as operating method for example, changes in dwell times; train speed and proportion of trains; or proposed changes in the infrastructure, for example, layout and number and size of station tracks, etc

1.2 Scope

This study is bounded to single track railways with passenger stations for commuter and regional trains.

Freight traffics are planned to pass or stop at station if needed for crossing depending on the operational requirements. This is a general investigation of capacity in response to important infrastructural and operational variants which is useful for new and long term planning instead of evaluating fixed infrastructure.

1.3 Delimitation

In this paper only three stations along single track are considered and the middle station is analyzed with different alternations of parameters for station and connecting tracks. The track lines connecting the stations are modeled free from gradient and curvature for simplicity and ease of analysis. This study is not subjected to any specific railway corridor as a case study; instead it investigates capacity of single track station in simulation environment by modeling fictitious stations and possible operational scenarios.

It aims to find out the parameters that influence the number of trains per unit time that can arrive and depart at station for the scheduled time table, infrastructural setups and other operational conditions. Two different timetables are analyzed in the study which are scheduled according to number tracks of the station under study. Lateness in arrival and departure, and average travelling time of trains between adjacent stations are used in determination of capacity for analytical calculation.

Two passengers and one freight services are run on tracks with each service being maintained to have its operational speed. Automatic train control of Swedish signaling system is used on the tracks and all trains are equipped with the same signaling system.

1.4 Outline of the thesis

This paper is outlined in five chapters. Chapter one presents an introduction of the thesis area and highlights the background studies. It also presents the scope and limitations which the study is bounded to. Chapter two describes the objective of the study and mentions the problems that the paper tries to address and why it is important to address the problems; followed by different definitions of the term capacity and how it is used in context of this paper.

In chapter three relevant literatures reviews in focus area of the paper are discussed. The two methodologies used in determining of capacity of single track station i.e. simulation and analytical approaches are explained. Infrastructural and operational setups for conducting simulation, and the parameters selected for different alternative cases are also elaborated. The analytical equation to calculate number of trains per time is introduced here using output parameters of the simulation. Results of different scenarios from simulations and analytical calculations are presented and analyzed in chapter four. Summary and conclusions are finally drawn in chapter five.

2. OBJECTIVE

2.1 Problem description

Even if single track lines and stations are inexpensive to build as compared to double track lines, the capacity output is so limited that investigating ways of maximizing number of trains in operation is essential. The initiating aim of this thesis is to answer how the capacity of single track stations is affected by factors that can be statistically variable. This is done by selecting basic infrastructural elements, operational and systematic parameters. This paper will identify the major invariants of station on single track that affect the number of trains arriving and departing at a station. The methodological objective is to model three fictive stations and single lines connecting them, to develop timetable for selected train types and perform simulation for some period of time. The station layouts and operational set ups are seen in different alternations.

2.2 Definition of Capacity

Railway capacity is an elusive concept for definition because the developments in the railway industry involve different professionals and stake holders who define the term capacity within their perspective and background areas. According to [1] the capacity of an infrastructure facility is the ability to operate the trains with an acceptable punctuality. Infrastructural managers build tracks and actually sell their line capacity to the operators. The operators determine the number and type of trains they can operate on the line based on the time table capacity and other operational considerations, which is defined by [2] as capacity as the capability of the infrastructure to handle one or several timetables. In the view of transport demand analysis, railway can be explained by its carriage capacity as number of persons per hour per direction, or tons per hour per direction along the line for passenger and freight trains respectively. Capacity thus cannot be defined exclusively and strictly as it is iterative process which depends on the train mixes, infrastructural setups and operational conditions. Therefore, capacity generally depends on how it is defined. This is mentioned in [3] as, ‘’capacity as such does not exist. Railway infrastructure capacity depends on the way it is utilized ‘’

2.2.1 Theoretical Capacity

‘’Theoretical capacity is the number of trains that could run over a route, during a specified time interval in a strictly perfect, mathematically generated environment, with the trains running permanently and ideally at minimum head way.’’ as in [4].

Single track takes the longest travelling time between any two stations as head way along the line for capacity estimation of line. Here it is adopted based on this statement; stations being a part of railway infrastructure, take the same definition for theoretical capacity. The theoretical scenario assumes trains to be homogeneous in their physical and operational dimensions such as speed and train length.

2.2.2 Actual Capacity

In practice a track is designed to accommodate mixed train traffic which has different operational parameters such as train length, speed, braking distance, traffic density…etc. As a result the overall flow lowers down and headway on the given line becomes variable which increases the journey time. Also, when there is a mixture of train services on a line there is higher chance that train delays propagate from one train to the other which substantially influences their planned arrival times at station. These reduce the theoretically available capacity.

3. METHODOLOGY

Different approaches have been developed for estimation of railway capacity. The most common methods are analytical methods, optimization methods, and simulation methods. In this paper, many scenarios are experimented with simulation method and are combined with analytical method.

3.1 Literature review

Several works in the area of railway capacity estimation and the methodologies are reviewed.

[4] sought main concepts and methods to access railway capacity and analyzed the main influencing factors. They emphasized the need for an automatic tool to integrate different empirical methods that can be utilized in order to arrive at better conclusion about railway network capacity. They presented a computer-based tool, the MOM system, which is designed for decision support requirements of Spanish railway administration that provides efficient and reactive management of railway infrastructures. This is a flexible simulation tool for the automated and optimized management of railway timetables in accordance with railway infrastructure, traffic, and user requirements. It also provides information on railway network capacity and on timetable robustness, helping managers to make better decisions.

They used periodic train analytical method described in their previous work (2005) to calculate the maximum capacity of railway infrastructure for periodic trains on selected route for assessment and they demonstrated the use of the optimization module of MOM system in obtaining the maximum capacity. They verified that both methods resulted the same number of trains per day and noted out that the tool performs further improvements by 'what if' analysis.

[5], like in this paper, have developed methods to measure the behavior of train schedules at station when trains are faced with external delays. In measuring the reliability of a timetable schedule, they varied the average size of exogenous delays as given input to the system and use simulation method in order to obtain distribution of secondary delays to test the fitness of timetables, in that a robust timetable is then one in which exogenous delays cause the least secondary delays. They explored how delays, platform allocation and reliability are affected by increasing exogenous delays using a computer tool called ATTPS (automatic train timetabling and platforming system). To see the effects of proposed changes, they also simulated timetables without exogenous delays and compare the results.

[6] has developed analytical modeling called SAMFOST (Simplified Analytical Model for Single-tracks) in order to study the influence of infrastructural design, timetable and delays on crossing time of trains on single track lines. He defined crossing time as ‘’the extra time needed to perform a crossing on a single track station compared to a double-track where crossings do not imply any extra time consumption.’’ His model has the basic assumptions that any two trains are independent before crossing, and following trains are fairly spaced on the line that crossings themselves are non interactive with each other. In the example shown in his paper part I, he models 9 symmetrical and identical crossing stations for two crossing trains and analyzed the sum of crossing times as a function of delay difference. It is shown that crossing time varies stochastically with delay difference in periodic manner; and with inter station distance. The author also shows that shorter inter station distance would result in smaller crossing time.

3.2 Analytical method

Analytical method employs simple mathematical expression to calculate capacity of a railway infrastructure. This is based on the critical section of a line that can take the longest travelling time based on which the number of train per time unit is estimated.

[7] calculate average sectional running time of a line based on train proportion to estimate the minimum and maximum ‘absolute capacity’ as they called it. Even if analytical method is literally simple and easy, we cannot arrive at a certain result directly without having a way to consider the actual operational circumstances prior to designing and constructing new infrastructures. The complexity of modern railway operation requires further mechanism such as simulation, or programming algorithm in order to estimate capacity of infrastructure with a better precision.

3.3 Simulation Method

Analytical method fails to estimate time delays of trains at stations, which are important inputs for capacity estimation. Simulation is an ideal way of incorporating complicated practical situations of trains’ performance, timetable and infrastructural configurations. More over it will allow us to have full control over values of input variants and easily see trends of capacity. Simulation tools may require very careful feeding of information in order to get reliable statistical output.

In this thesis, RailSys is used as a tool for simulation. This is a German simulation tool for modeling and evaluation of train operation. The infrastructural package of the software uses nodes to form links which are attributed to different measurable specifications such as length, maximum allowed link speed, block sections etc. The timetable and simulation part is for developing timetable by selecting types of trains with their signaling system, setting up stopping patterns and time allowances for possible lateness etc. It also enable us to create perturbed timetables and run the simulations on the tracks and stations which have been designed in the infrastructure manager. The statistical output of the simulation is filtered and analyzed on the evaluation manager of the tool. The following diagram shows the executing procedure in RailSys.

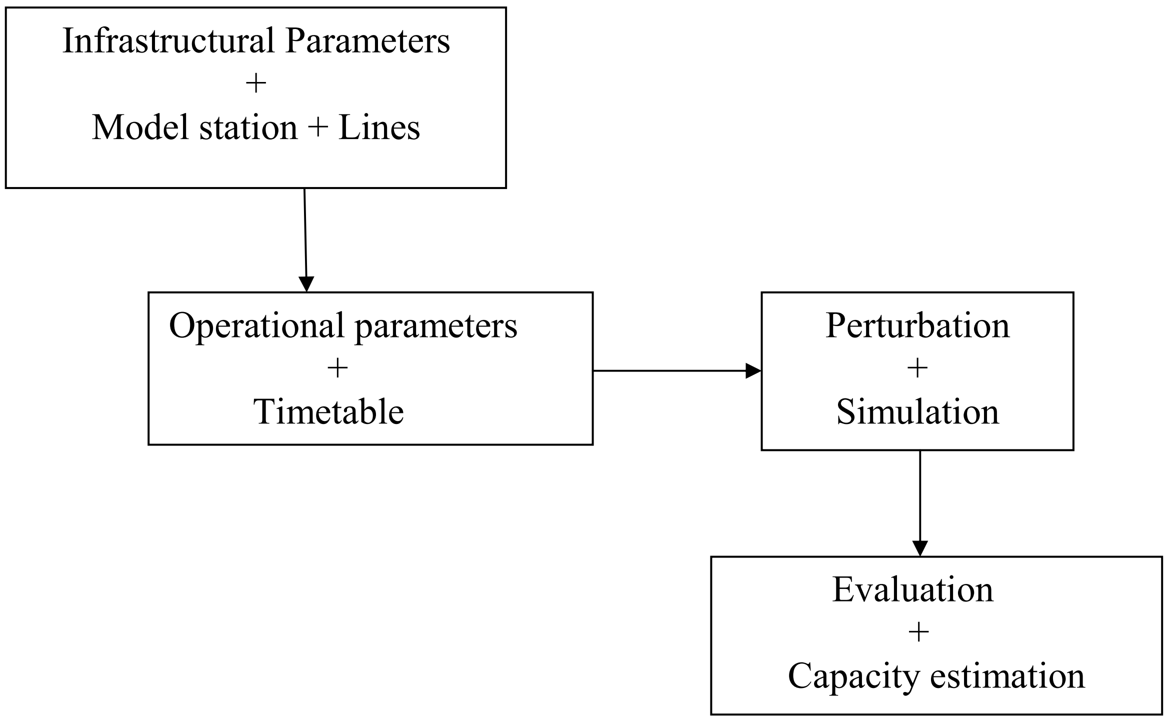


Fig. 1 Procedure in RailSys

3.4 General settings

The general setting starts by building basic infrastructure of the line and stations with initial dimensional setups which includes distance between station, size of station tracks and block sections. The constituting parameters in the initial setup are varied under two timetables.

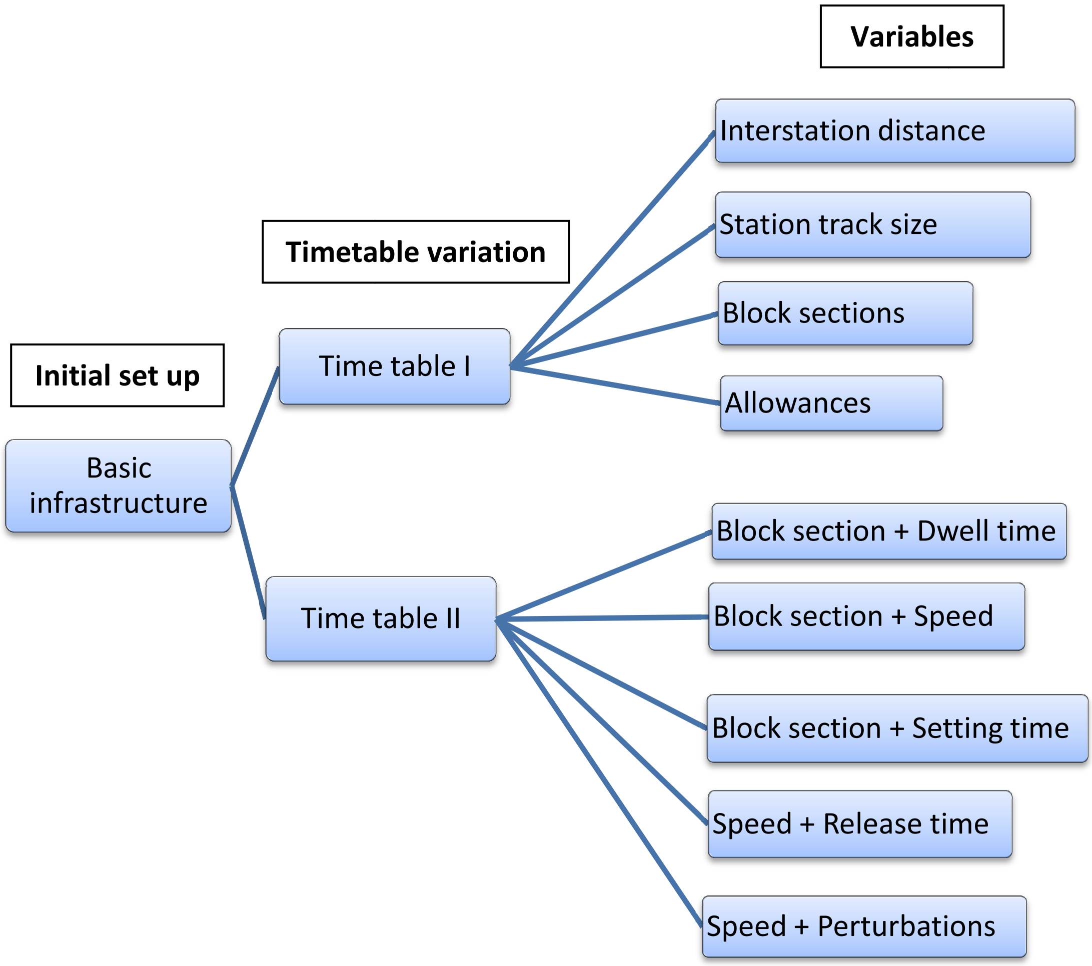


Fig. 2 General variation (work) set up

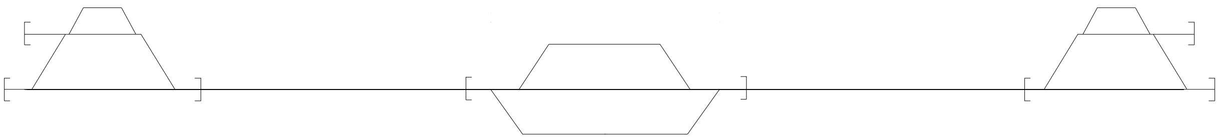
As shown above, two general scenarios are studied with respect to the timetables. Both scenarios contain experiments undertaken with different parameters *(see fig.2)*. Among many other factors, these parameters are selected for variation because they are representative and determinant factors from infrastructure, signaling system and trains characteristics. In the first scenario capacity is studied by variating a single factor at a time, while the second one combines infrastructural and operational parameters at the same time. The latter aims to consider the combined effect of operational parameters. The following subtopics describe the general setups of infrastructure, timetable and signaling system in both scenarios.

3.4.1 Infrastructure

Three stations are modeled along a single track and the middle station which is studied for capacity is situated at equal distance from the outer stations. This is the case in all scenarios. Station distance is contained as one of the variables and seen in the first scenario with a minimum assumed distance taken to be 15 km. Number of tracks for station B is different for two general situations.

In the first scenario station B is modeled with 3 tracks, while in the second one with 6 tracks. This change of number of tracks creates the variation of number of trains and timetable schedules in the two different cases.

The end stations have fixed dimensions and the same number to tracks in both general scenarios and all experiments. To simplify and limit number of variables, geometric factors such as gradients and curves are omitted from the variables. Stations and tracks are assumed to be in straight line. The following diagram shows configuration of the three stations.



Station A *Station B* *Station C*

Fig. 3 Single track line with 3 stations.

3.4.2 Timetable

Three types of trains are scheduled in the timetables as shown in the following table.

Table 1 Trains specifications used in RailSys.

Train type	Traction unit type	Length [m]	V_{max} [Km/hr]	Runtime allowance [%]	Standard breaking rate [m/s^2]	Signaling system
Regional	RC6_6v	174	160	3	0.6	MP, ATC
Commuter	X 10_1	200	140	3	0.6	MP, ATC
Freight	RC6	150	90	3	0.4	MP, ATC

Train stops

Commuter trains are scheduled to stop at all the three stations while regional trains only stop at middle station for scheduled dwell time, both for boarding and alighting passengers, but freight trains do not need to stop at any of the stations except for crossing/waiting for other trains to clear the line depending on the timetables considered later. All the trains are set for the same priorities over station tracks. In the timetables seen in next sections, stopping patterns of all trains at stations A and C are the same but at station B all types of trains should stop. The stopping patterns at stations are independent and do not affect one another.

Cyclic timetables

A cyclic timetable is designed to contain the trains with different frequencies. The time length of the cyclic timetable varies according to infrastructure variant considered in each specific scenarios such as inter station distance or operational factors which affect the dispatching times of trains from the outer stations. The line for train routes is bounded by stations A and C where trains depart and end *(see fig. 3).* All the fleets are two ways traffic.

Two cyclic timetables are designed respective to the two general situations. The cyclic timetable contained in the first general case is scheduled with total of 10 trains in which 5 trains are dispatched from end stations one after the other. The trains departing from end stations are of the same type and they meet at middle station. Arriving trains enter simultaneously at the mid station, but in some cases one of the trains arrives few seconds later than other train as it may depart from side tracks of outer stations, i.e. a train departing from main track arrives relatively earlier than the train in opposite direction. Alternative tracks for routing of each train in all station are the same during simulation. Before a train enters the stations the signaling system checks the availability of tracks and the train is directed to occupy a free track. Track selection priority at a station for all trains is designed in the simulation tool in such a way that main track being the first choice and the outer track being the last choice.

Commuter trains are scheduled with more trains in the cycle time to exemplify what is actually in real operation such as the main line operation in Sweden. For example, commuter trains to suburbs of Stockholm and Uppsala departs from central station every 15 and 30 minutes respectively when regional trains departs few times a day depending on the distances of destinations [8].

In this timetable, only one freight train need to stop at the middle station until the other freight train crosses the station as indicated in *fig.4*. The freight trains are included in between two commuter trains to incorporate the effect of interactions of trains that would cause of delay propagations later in simulation part.

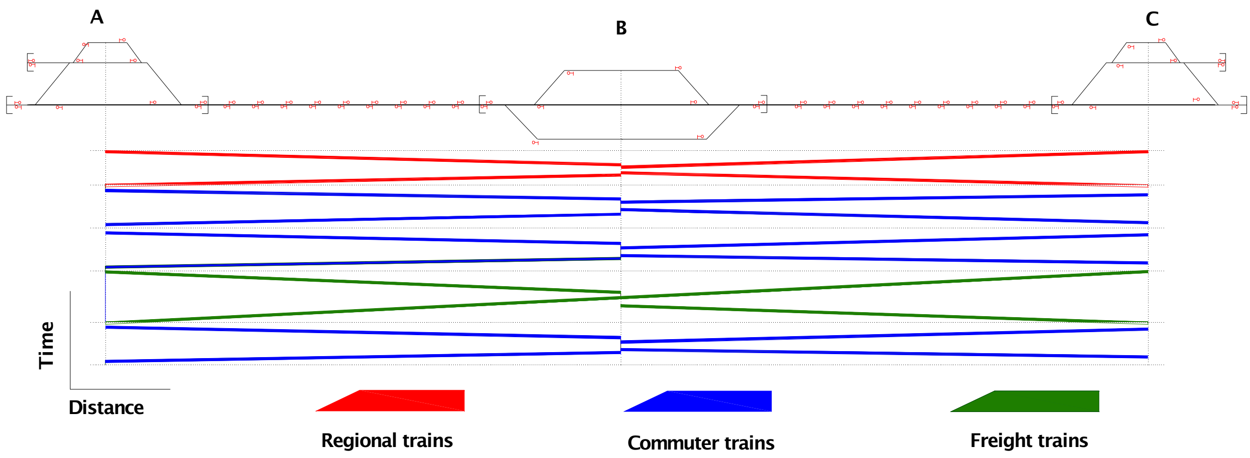


Fig. 4 Cyclic timetable -1

Supplement of 5 seconds is added between the arrival and departure of trains at end stations. This buffer time is too small to absorb big delays but the idea is to increase the safety of trains' routings by making sure that the arriving train is completely at platform before another train leaves the station.

In the second timetable groups of trains containing same train types are scheduled to depart from outer stations and meet in the middle. The main idea in this timetable is to see the effect on capacity of doubling the number of tracks in the middle station and thus run more trains per hour per direction by allowing the timetable to accommodate 3 trains from each direction, meeting of 6 trains at mid station.

The cyclic timetable contains two groups of trains. The first group of trains is composed of 1 regional passenger and 2 commuter trains, and the second 1 freight and 2 commuter trains. It would be possible to make only one group of trains which could contain 3 trains, one from each type of trains, however, it may not be realistic to have equal proportion of each type of trains in a cyclic timetable. As stated in the first timetable, usually commuter train service operate more frequently than other type of trains. Therefore, in the case of this timetable it is necessary to have two groups of trains in order to increase the frequency of commuter trains.

Since there are mix of services, and this is a single track operation ,it is impossible to keep regular headway between commuter trains. It is preferred to operate two commuter trains after each other to avoid longer time gap that would happen if other train type is run in between them. This paper considers single unit trains and train conjugation is not covered. The conjugation of trains is one of the ways to increase capacity specially in single track line which may be difficult to run trains with as high frequency.

Therefore, it is important to note the possibility of conjugating the two commuter trains running one after the other and increase the lengths of platforms at stations to accommodate their lengths.

Unlike the first timetable, both freight trains need necessarily stop at the middle station until commuter trains route out of the station. The groups of trains depart from end stations with a minimum head way, and a buffer time of 2 minutes is supplemented between the groups of trains. That is between the last train of the arriving group and first train of the departing group at the end stations.

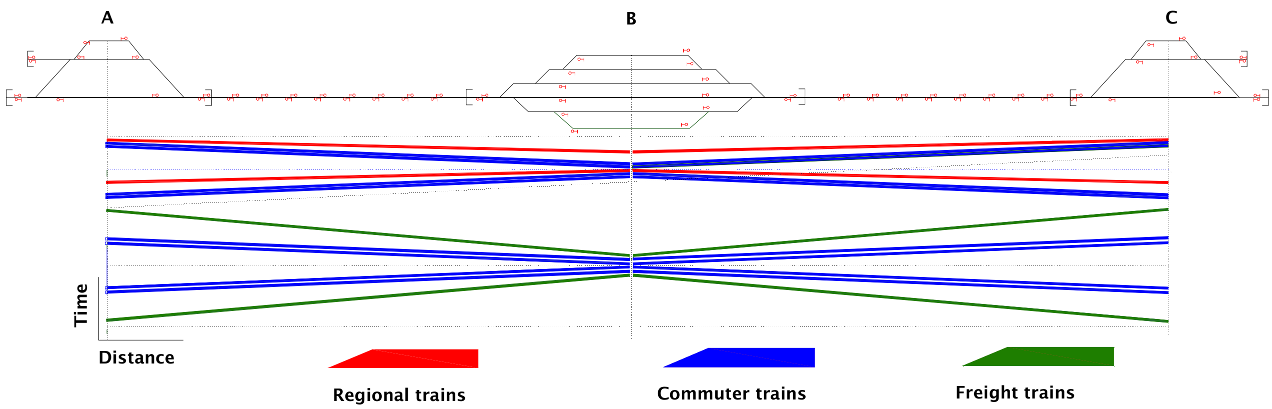


Fig.5 Cyclic timetable -2

Table 2 shows the proportion in train composition of the cyclic timetables. Commuter train run is made to take highest proportion since they are more frequent ones in real operation.

Table 2 Train proportions

Train type	**Number of train runs in both direction and proportion (%)**	
	Cyclic timetable 1	**Cyclic timetable 2**
Regional passenger	2 (20%)	2 (16.7%)
Local commuter	6 (60%)	8 (66.7%)
Freight regional	2 (20%)	2 (16.7%)
Total	**10** (100%)	**12** (100 %)

3.4.4 Signaling system

The Swedish signaling system ATC-S is used for infrastructures and trains in different alternatives. This signaling system is based on fixed block and has two subdivisions: ATCS-1 which is used on secondary lines and ATCS-2 which is common on main line of Swedish rail network. In the case of ATCS-1, stair case type of speed reduction rule applies before a train under control should stop at the nearest stop signal. This is accompanied by track side signal aspects showing warning, speed limits and information of the upcoming signals situations by pre- signals. Trains' locations are known by the fixed block section they occupy. In the case of ATC-2, a given train regulates instantaneously the speed reduction curve in such a way that it will stop few meters before the stop signal which protects a train in front of it. ATCS-1 signaling system is used in this paper.

As indicated in *Table1*, all trains are equipped with M/P, and ATC signaling system. A group of 2 ballises are installed in each block section for communication media between the track and the trains.

3.4.5 Simulations

Before carrying out simulation of timetable, entry perturbation is induced to trains entering to the line at the two outer stations in order to fit simulation with real life situation of train delays. This is a primary delay to take in to account of possible failure of vehicles and signals that can possibly delay the trains entering the line. In case of delays, it is important to distinguish the two kinds of delays, primary and secondary delays.

Primary delays are initial delays caused by external factors mentioned above while secondary delays are propagation of delays from initially delayed trains to other trains in the system. In the first and second part of simulations it is assumed that 20 % and 10 % of trains respectively, would be late to enter the network at station A and station C by 1 minute averagely , and maximum lateness being 5 minutes. The distributions of the primary delays are assumed to be negative exponential. First and second parts of the simulations are belonging to timetables 1 and 2, respectively.

Three cyclic timetables per day are simulated for a total of 120 days and the trains included in the middle cyclic timetable are selected for evaluation in the first part of simulations where only one variable is studied. In this timetable, the middle trains(the second cycle) are selected for evaluation in order to avoid over estimation of capacity due to lower average values of lateness parameters that would result if all trains were included in the evaluation. For the second timetable scenario, evaluation of simulation is done for two cyclic timetables for the same period of time.

3.5 Variants

Since capacity is based on how the infrastructure is dimensioned and usage of operational setups, and external factors affecting the operation, its determination requires a number of variants to be considered. These are discussed below.

Track Size

Track size is the distance between in routing point and out routing point in station area. It is used by trains to stop at platform for passenger exchanging or crossing. *(see fig.6)*. It dimensions the size of the station and the minimum effective length of station track being greater than the length of the longest train in the fleet.

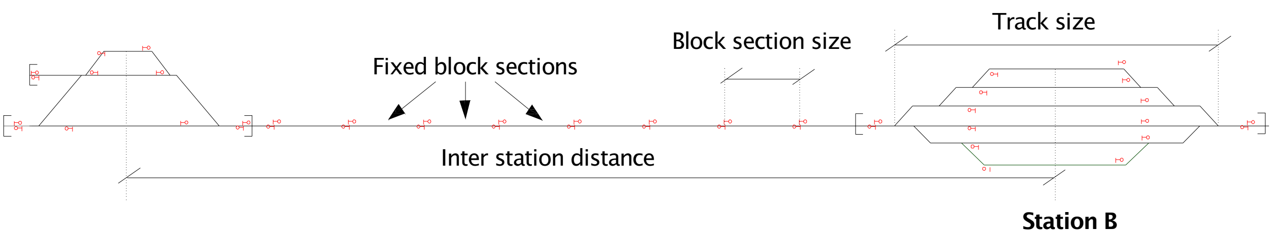


Fig.6 Infrastructure variants

Inter station distance

The distance between stations is one of the important parameters. Shorter inter station distance may limit speed of train along the line because of requirement of trains for adequate distance for accelerating and breaking prior to entering a station. In case of mixed traffic with sound speed difference, the station distance should be optimized to get good capacity output though it might not be always easy in reality.

Block sections

In fixed block signaling system which this paper considers (ATCS-1), the sizes of block sections are major dimensions that control the spacing of trains between stations. This is the division of the distance between two stations into equal parts which a train occupies, and these sections are separated by track side signals. The sizes of the block sections should accommodate the longest train and breaking distance of trains.

The number of these segments is varied at constant inter station distance to see the effect on trains' performance over different sizes of the sections. The size of the block sections next to the station are investigated to affect train breaking performance before entering station area.

Route setting and route release time

The safety of trains during occupation of track section is ensured by the interlocking process of the signal system.

Route setting time is a time required to make the signal green before a train arrives at the entrance point of the block section. The driver needs sighting time to see the pre-signal to get information about the main signal. The train uses the approaching time from the pre-signal to main signal to enter the block section. The running time is time the train needs to complete the full block section. These are components of blocking time as indicated in *Fig.7*.

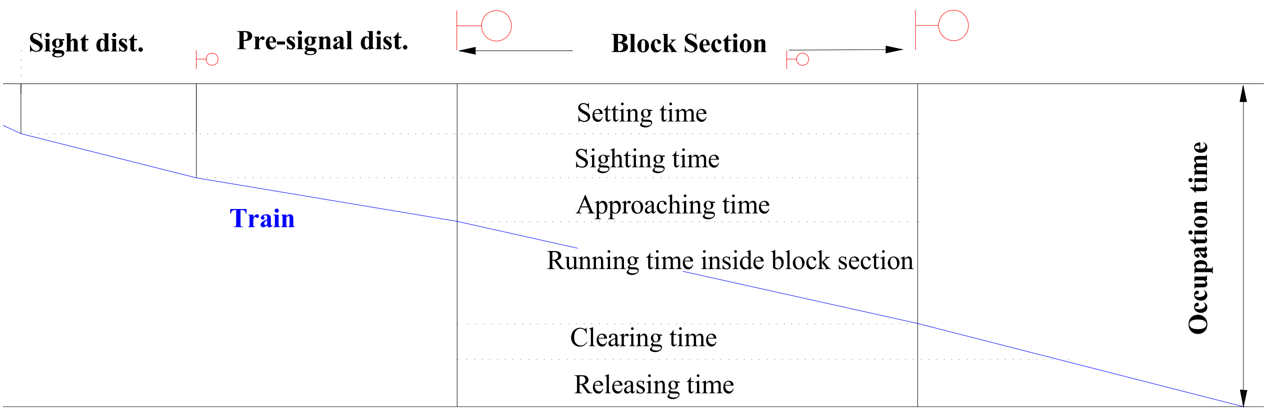


Fig. 7 Blocking time of a train [9].

Clearing time depends on the length of the train since it is the time a train requires to take the whole of its length off the block section. After the train clears off the block section some time elapses to unset the block section and set it for new occupation, which is called release time. Therefore variation of release time has impact on time spacing between trains, and is worth seeing how it affects the routing of trains in station.

In this study, distant signals are set 1000 meters before the main signal and release contacts are located exactly at signal location in infrastructure setup. Release contacts are timers which are used to free a section after a train has completely passed signal point.

Trains' speed

In order to get maximum output of operation, trains should have same magnitude of speed. However, this kind of operation can only be done along routes which are dedicated for one type of traffic such as metros in a city unlike trains considered in this study. Individual trains' speed has been varied from 50% to 100% in combination to other parameters such as release time which can both possibly affect the interlocking process of the signaling system.

3.6 Output parameters for station capacity

Many parameters for stations and lines can be found as a result of multiple simulations. These are average values for selected trains for analysis at station B for which this thesis aims to determine the capacity. The following output parameters are extracted from simulation statistics. The first three are directly used in analytical estimation of capacity, and the other two are used as performance indicators of trains.

Travel time

Travel time is the average time a train spends between departures at one station to arrival at the next station. It is affected by blocking time of the signaling system, speed and breaking capability of trains. Travel time can be supplemented with additional time so that trains can use it to recover from lateness in arrival should it happen; or if trains are not late they need to wait along the line to keep scheduled timetable.

Dwell time

Dwell time is the length of time trains stop at the station for boarding and alighting passengers or waiting for other train to cross the station. As can be seen in a few experiments in this paper, in single track stations trains may be stopped longer than the actual time required for boarding, alighting passengers and crossing of trains. This is due to the existence of common track in station area for departing or entering to a station. Dwell time also has great dependency on the signaling system used in the operation.

Lateness development at station

Lateness development at station is the difference between arrival lateness and departure lateness which is the net time a train stops at a station in excess of the scheduled dwell time. In other words, it is additional delay developed by a train at a station. It is one of the parameters used in the analytical equation of capacity in this paper. As lateness development increases the capacity of the station drops since few trains are holding the station for longer period of time.

Extended stops

Since trains are run on single tracks, they cannot depart from a station before the online train arrives. Thus, the occupation of the line by late trains induces extra dwell time to trains at station until the line is cleared, which is extended stops. The extended stops at station in turn propagate to other trains which are scheduled to occupy the same station.

3.7 Calculation of station capacity

The first simple analytical method was introduced by Union international des chemins de fer in 1979.

It is for calculating the capacity which is available for single track line with the assumption that all trains run in the same direction. The equation calculates capacity as a given amount of time divided by the shortest time of train succession.

$$Capacity = \frac{Time\ interval}{D + M} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

Where D is the shortest possible time of train succession and M is a safety margin that insures stable train operations. However, this equation holds if running trains on the track should have the same safety distance. This is not the actual scenario when the track is used by different train types such as the situations considered in this paper. Therefore, the basic concept of the above equation being unaltered but is adjusted to consider the three types of trains contained in this study.

The length of time trains spend over a given part of track infrastructure is cumulative output of many factors and is basic measure of capacity. The infrastructure layout, operational set ups and speed of trains are some of the factors controlling the occupational time of trains. Therefore, in order to estimate actual capacity of station we need to include the running time of trains between stations and the dwell time. As a train moves from station A to C it spends a total time that comprises three components, vis. travelling time, scheduled dwell time at station and the lateness development at the middle station(B).

The average travel time and lateness developed at the mid station are results of simulation which already incorporates the perturbations. Perturbations are introduced as entry delay at outer stations , therefore the delay development at the middle station is the consequence of the perturbation and induced knock on delays. The average travel time for all trains simulated over the track between stations A and station B is extracted from RailSys as simulation statistics, while scheduled dwell time is taken directly from the scheduled timetable. *Fig. 8* shows the time components of train path between two stations.

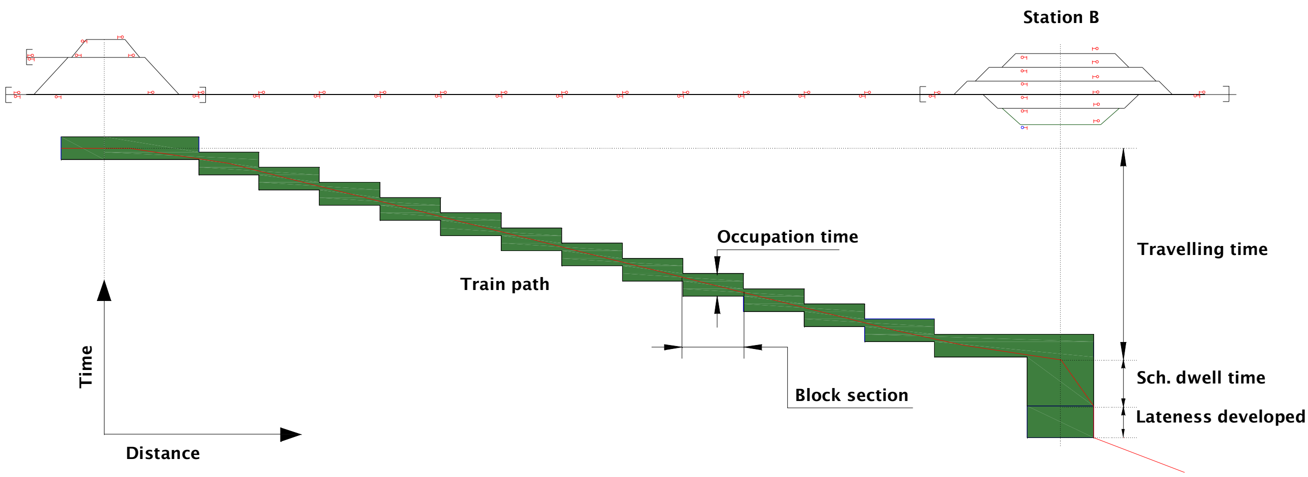


Fig.8 Time components of train path between two stations

Since station distance between A and B, and between B and C are equal, we can assume that trains will take same average travelling time along the two segments. Therefore, the total time an 'average' train will consume to travel from end to end station will be

$$t = t_t + t_d + t_l + t_t = 2t_t + t_d + t_l \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

Where, t = total time, A to C, minutes

t_t = travel time , A to B, minutes

t_d = dwell time at B, minutes

t_l = lateness development at B, minutes

$= t_{ld} - t_{la}$

t_{ld} = lateness departure at B, minutes

t_{la} = lateness arrival at B, minutes

Therefore, analogously with equation (3.1), the capacity of middle station will be,

$$C_{ave.} = \frac{Time\ interval}{Total\ time} = \frac{60}{2t_t + t_d + t_l} \quad \dots\dots\dots\dots\dots\dots (3.3)$$

C_{ave} = the average number of trains per hour routed through a station B in one direction.

The total number of trains per hour is the sum of the two directions. Equation 3.3 is utilized to determine the number of trains arriving and routing out of station B, and the trend of the capacity is studied in conjunction with other variable considered in the specific scenarios.

4. EVALUATIONS OF RESULTS

The performance characteristics which are results of the simulation may be determined either for a selected train or types of train. The performance indicators are categorized for lines and stations in RailSys. Parameters under lines include scheduled and actual travel times, delays in travelling, while output parameters for station contains data related to punctuality, lateness within station, and dwell time extensions. The important parameters as input to equation 3.3, and other most relevant evaluation parameters are filtered out for comparisons.

4.1 Scenario 1

The following subsections present and discuss the results of variations of parameters under the first timetable.

4.1.1 Variation of number of block sections

The goal of this scenario is to see the effect of block section size on cumulative number of train routings through the middle station. All other parameters are being kept unchanged, see table 3. The basic idea in here is to see how the operational occupation of trains in varying size of block sections affects the arrival time of trains at a station which directly impacts the number of trains that can use the station per time unit. The dimensions of the physical infrastructure and operational quantities are presented in *Table 3*.

Table 3 Basic setups for scenario 1

<table>
<tr><th colspan="2" rowspan="3">Infrastructural</th><th colspan="8">Operational</th></tr>
<tr><th colspan="2" rowspan="2">Interclocking time [Sec.]</th><th colspan="2" rowspan="2">Trains' speed [Km/hr]</th><th colspan="2">Dwell time [Sec.]</th></tr>
<tr><th>Sched.</th><th>Min.</th></tr>
<tr><td>Interstation distance</td><td>15 km</td><td>Setting time</td><td>5</td><td>Regional</td><td>160</td><td>45</td><td>45</td></tr>
<tr><td>Station B track size</td><td>400 m</td><td>Release time</td><td>5</td><td>Commuter</td><td>140</td><td>45</td><td>45</td></tr>
<tr><td></td><td></td><td>Point setting time</td><td>10</td><td>Freight</td><td>90</td><td>105</td><td>30</td></tr>
</table>

The following diagram shows the relation between total number of trains that can arrive and depart at station B in both direction with varying number of block sections.

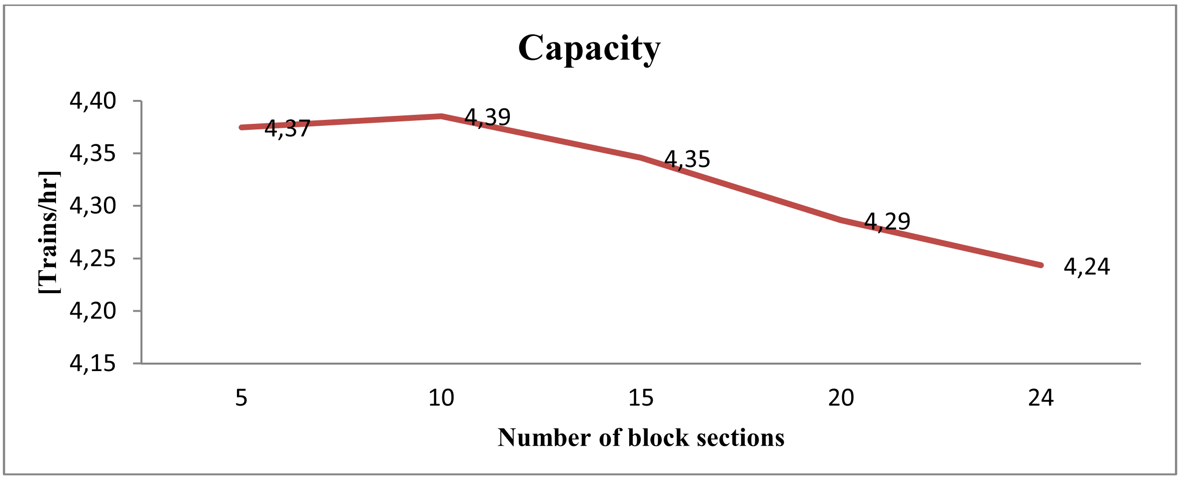


Fig. 9 Capacity output as function of number of block sections

It can be seen that the number of trains slightly increases between five and ten block sections and starts to decrease afterwards until 20 block sections and then shows up a trend of decreasing. The capacity becomes lowest as the size of block section gets smaller due to increment of the extended dwell time of trains at station B as shown in the fig.10.

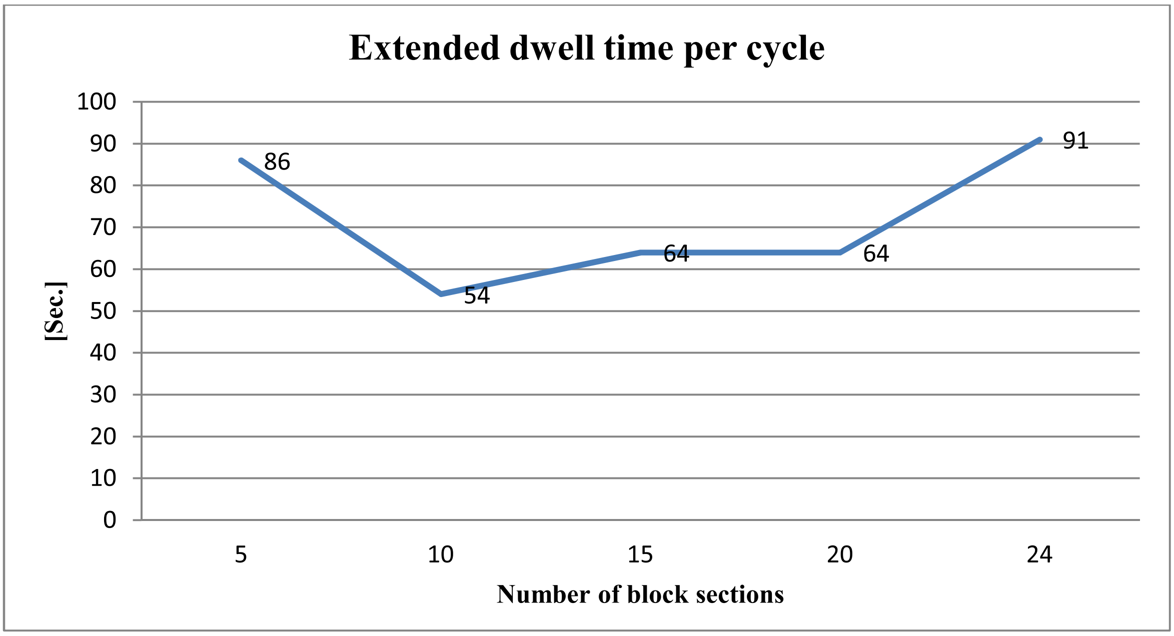


Fig.10 Extended dwell times at station B per simulation cycle

4.1.2 Variation of block section size adjacent to station

In this scenario variation of the size of block section next to the station is considered under constant inter station distance. The aim is to see how this distance affects the speed/breaking performance of trains arriving at the station.

The effect can be explained by travel time or lateness in arrival at station. In this block section, there is no early restriction of speed until they enter station area, however, the variation is not found to change the arrival time of trains.

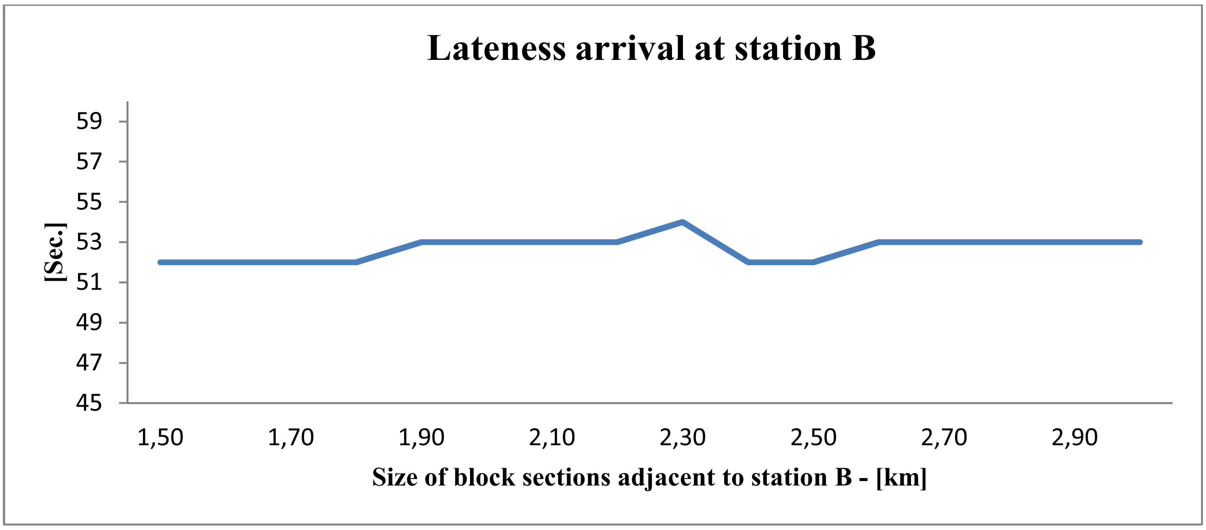


Fig. 11 Lateness arrival at station B as a function of size of the adjacent block sections

The result shows that variation of block section size next to analyzed station has no visible effect on the number of trains arriving and departing at middle station as illustrated by the following graph. This may be owing to the constant breaking performances of trains when entering the station area, or the time saving gained by avoiding early breaking (which can be achieved by making short block section next to the station) is not changing the capacity.

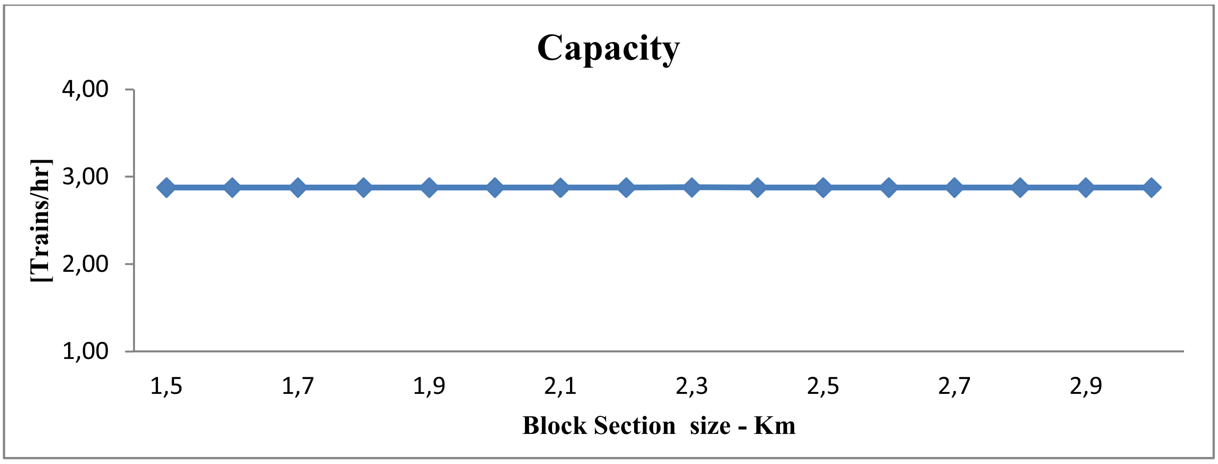


Fig. 12 Maximum capacity at station B as a function of size of adjacent block section.

The average travelling time of trains and punctuality are also quite uniform. We can say that for single train running between stations on single track, size of the adjacent block section does not affect train performance and capacity.

4.1.3 Variation of inter station distance

The distance between stations is the main parameter controlling the travelling time, and it has inverse relationship with capacity of a given infrastructure.

Distance is varied between 15 and 55 km, other parameters being unchanged. *Fig.13* illustrates capacity for the average speed of trains. The number of trains per hour starts to grow at the beginning and declines after around 20 km. The capacity is low for inter station distances less than 20 km because of the presence of deadlocks in the timetables during simulation. Deadlock is a situation when two trains face each other along a single track. The results of multiple simulations for inter station distances of 15 km 17,5 km and 20 km are found to have deadlocks for 118 , 113 and 7 days respectively from a total of 120 operational days considered for simulation. Contributing factors for initiation of deadlocks in this case are exceeding number of trains in the time table and diversity of services which have significant effect on these short inter station distances. 'The trains involved in deadlocks are subjected to very high delays,' Rmcon [9, p.445]. These trains enter into situation of deadlocks as a consequence of previous trains in the timetable which encountered entry delays at stations A and C.

RailSys is set up to cancel the trains with deadlocks and continue with the next trains in simulation, but before the next trains depart, the deadlocked trains along the line are taken back to the stations where they departed. These trains consume additional time and in effect elongate the departure times of following trains, inducing development of delays at the stations. Thus , the effect of deadlock is the main cause for capacity minimization for the inter station distances less than 20 km. As the inter station distances grow more than 20 km, deadlocks are not observed but the timetables accommodate fewer number of trains per time due to the increasing average travel time of trains, and capacity drops. *See fig. 14*.

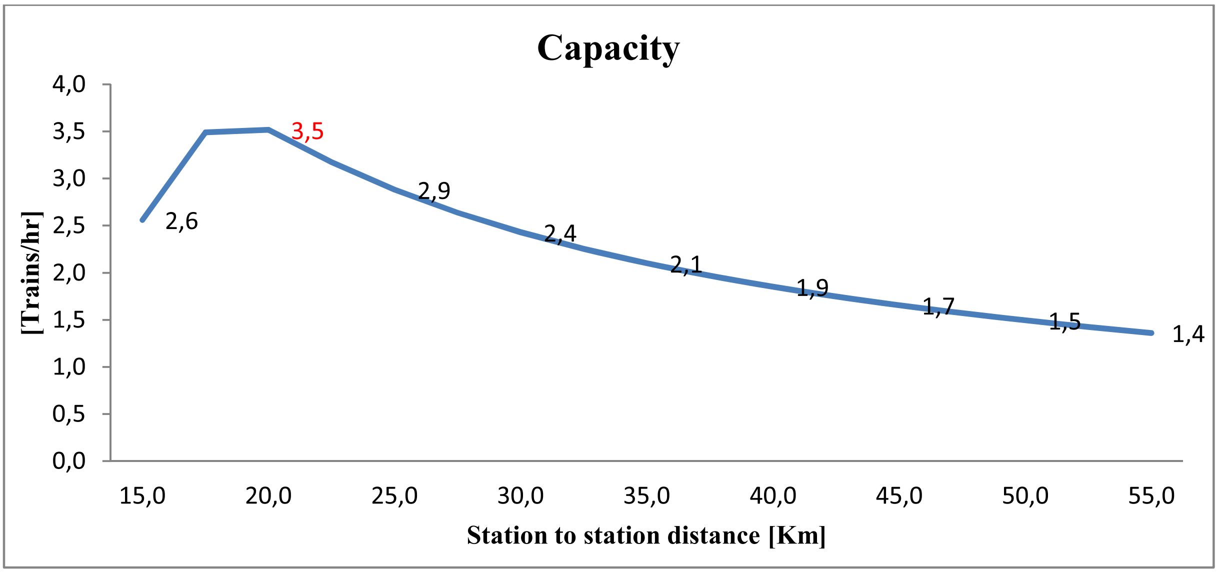


Fig. 13 Capacity at station B.

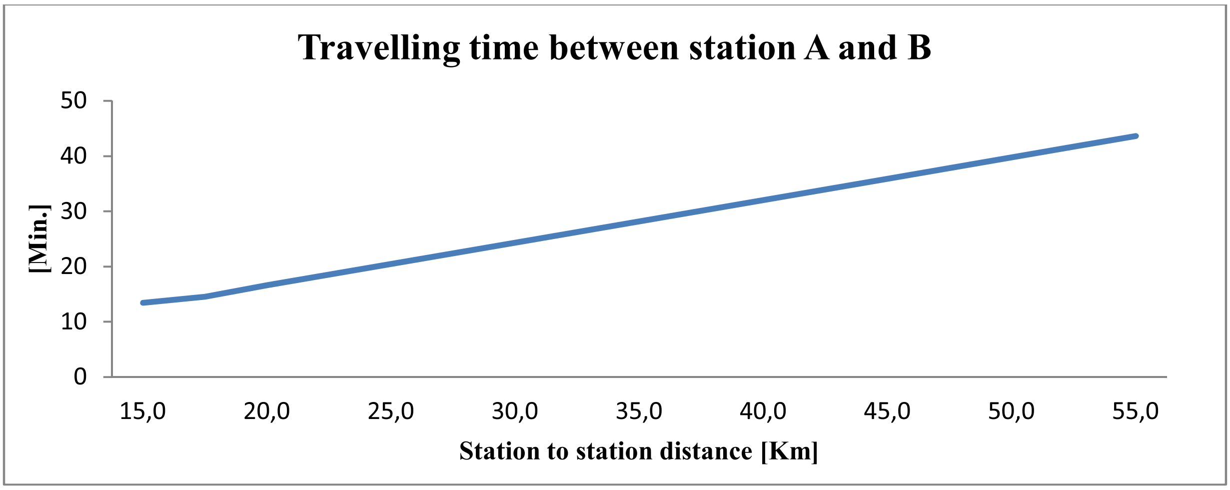


Fig. 14 Travelling time between station B and end stations

For this specific scenario, 20 km gap between stations is the optimum size that gives good capacity.

Fig.14 indicates that there is linear relationship between the distance between station A and B and travelling time for any average train (R^2 = 99.97%) which directly shows that each train performs persistently at constant speed irrespective of the variation of distances. The speed-distance diagrams for trains are shown in Appendix C.

On the other hand, unscheduled stops is controlling factor for the number of routings for the smaller distance of station. As the unscheduled dwell time increases between 15- 20 km, the capacity decreases accordingly; however, as the stations gap increases the unscheduled stops becomes constant and does not affect the capacity.

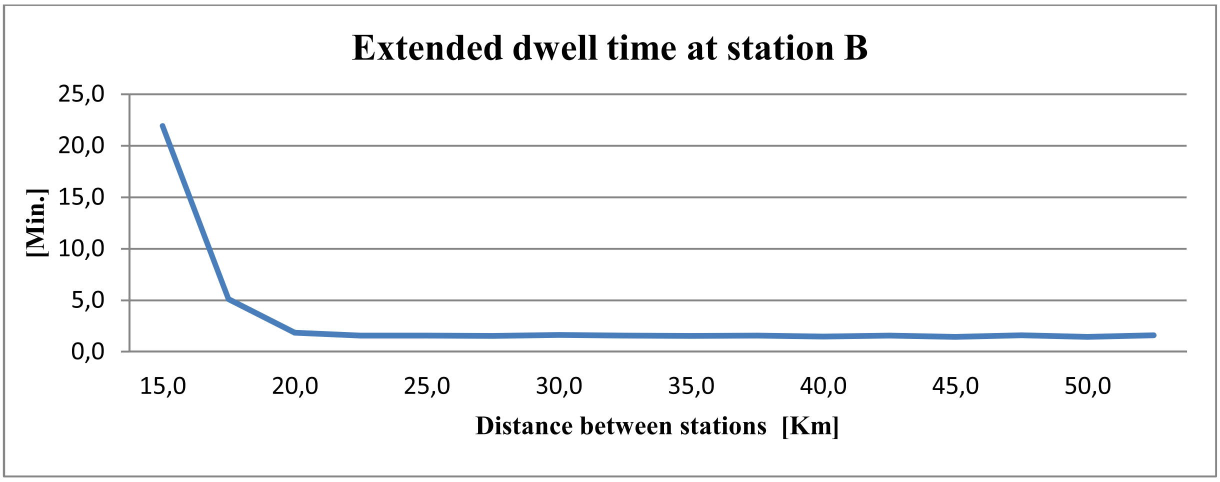


Fig. 15 Extended dwell time at station B.

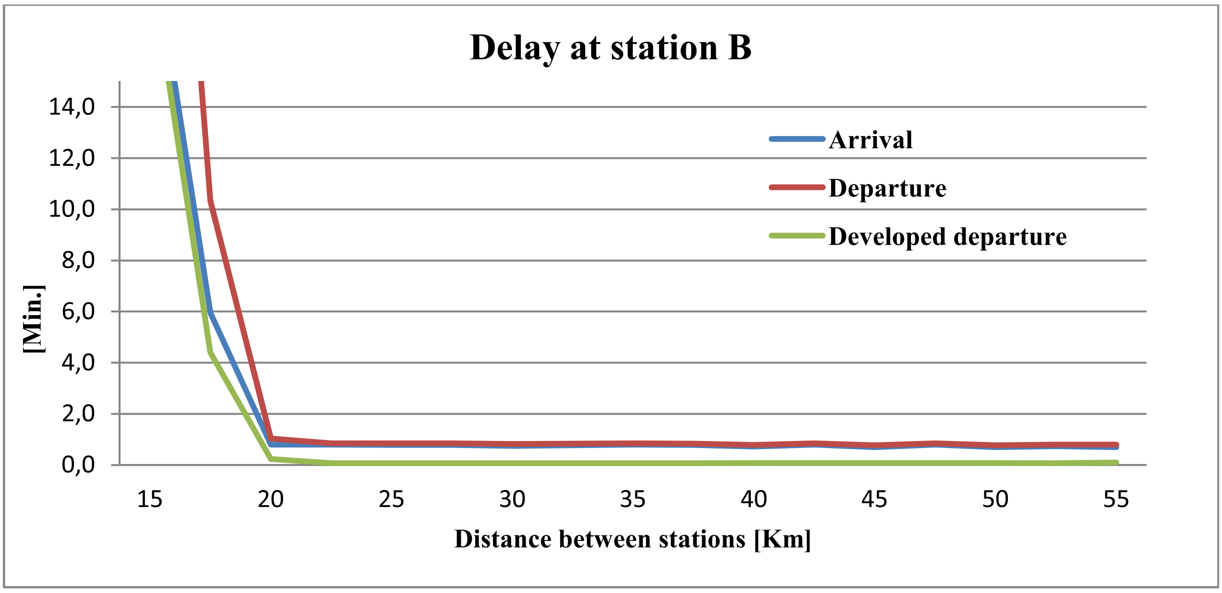


Fig. 16 Delays at station B

The extended dwell time and delays at station B show up similar curves and turning points. Before the turning point, 20 km, the effect of disturbance (knock on delays) is significantly affecting the punctuality of trains.

4.1.4 Variation of station track size

In this alternative the overall length of station is varied from 300 to 1000 meter and the simulation result shows no deadlock in the operation. Allowable speed along the main track is the same as the line between stations, and restricted to be 40 km/hr along other tracks within station. The capacity, departure lateness and level of occupation are plotted against the track size.

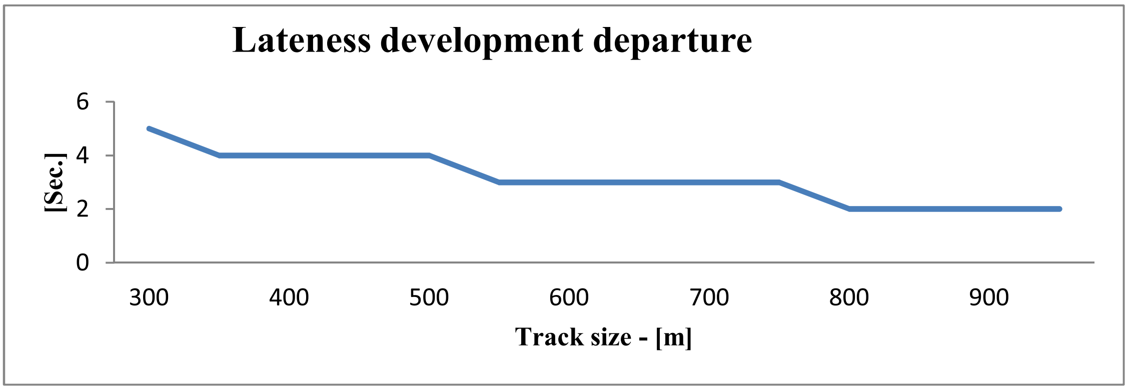


Fig. 17 Lateness development departure at station B as function of track size

As the length of the track increases the lateness development is varying only between 2 - 6 seconds, which has low significance in capacity of the station as compared to the average travelling time. Even if the change in number of routing of trains as a function of track size is not significant, there is a relationship which indicates that increment of station track length reduces approximately linearly the routing capacity of a station.

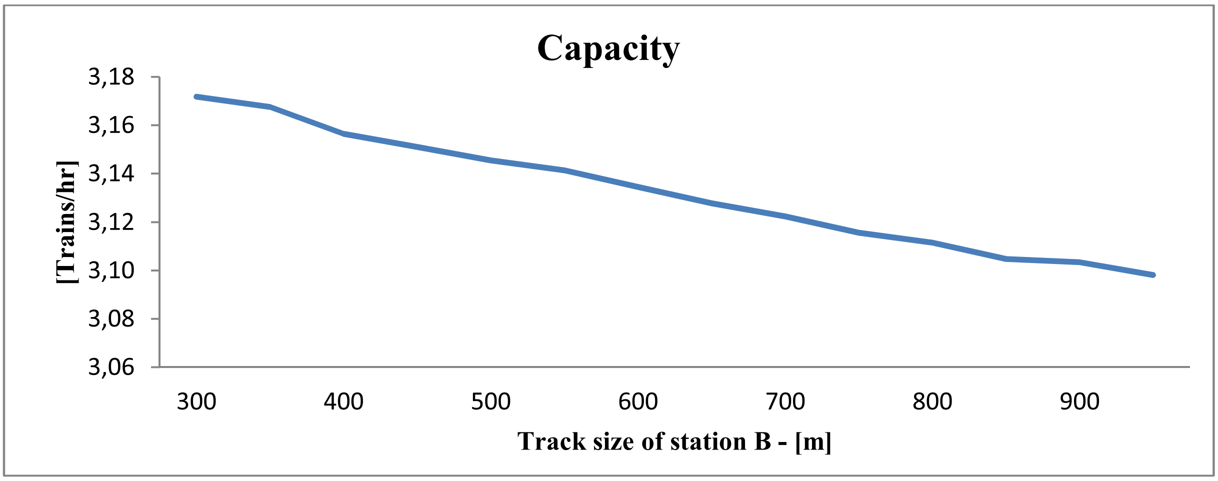


Fig. 18 Capacity at station B

4.1.5 Variation between allowances/buffer time.

Allowance is time that can be added between trains in a timetable in order to avoid or minimize the effects of disturbances and hence maximize the on time running of trains. Reliability of timetable usually increases with supplement of allowances.

The following setups are designed in this alternative before the simulation of timetable is run. The trains listed in the following table are from one cyclic timetable.

Table 4 Setups in allowance variations

Infrastructural setups			**Operational setups**					
			Interclocking times [Sec.]			**Trains' max. speed [Km/hr]**		**Sch. dwell time [Sec.]**
Interstation distance	25 km		Setting time	5		Regional	160	60
Station track size, B	400 m		Release time	5		Commuter	140	60
Block section	2,5 Km		Point setting time	10		Freight	90	105

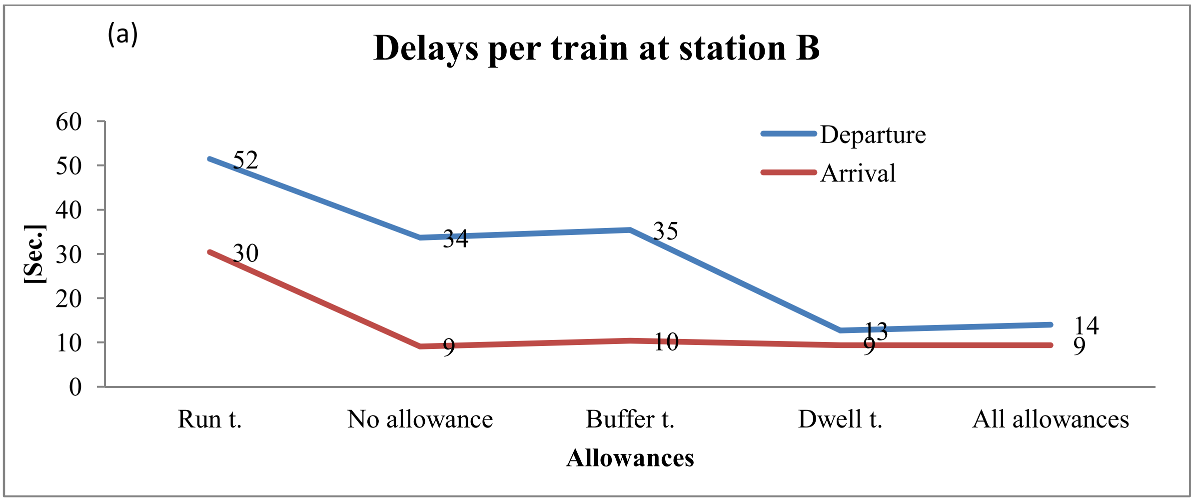
Variations in previous scenarios have been checked without any allowances in the simulation of timetables except the standard running time allowances which is 3% of minimum running time reserved with each train type in order to catch up delays owing to driver's behavior. The aim of this variation is to quantify the impacts of three different allowance types on capacity at station and trains performances.

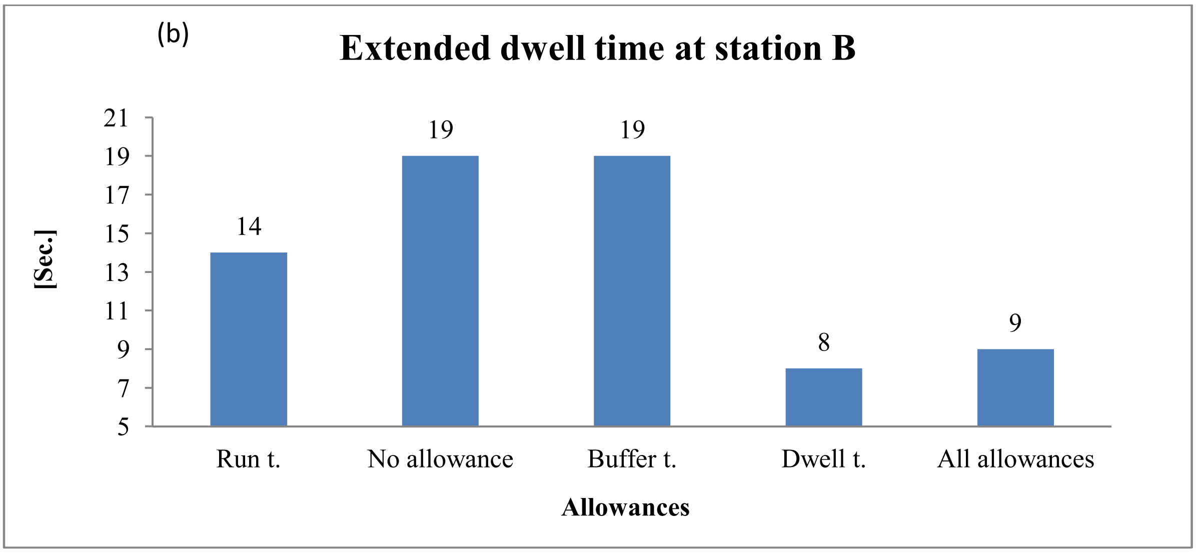
Each type of allowance in this scenario is treated over the same perturbation distribution that 20% of the trains take entry delay at stations A, and C at average and maximum lateness of 1 minute and 5 minutes respectively with negative exponential distribution. At their stopping stations, regional and commuter trains are assigned with 60 sec of scheduled dwell time, and 105 sec for those of freight trains. For consideration of dwell time allowances, regional and commuter trains dwell for 25 sec. and freight trains for 1 sec. at station during delays in arrival. Similar amount of allowance is used in running time case as shown in *Table 5*, and all the allowances are used 100% during simulation. Though allowances are different in ways of application, they have been set for same length of time and are compared by their recovering effect of lateness, and by how they influence the capacity.

Table 5 Allowance alternatives

Trains	**Allowance alternatives**				
	1 **Runtime** [Sec.]	2 **Dwell time** [Sec.]	3 **Buffer time** [Sec.]	4 **All combined**	5 **No allowances** (Base line)
Regional	35	35	35	1,2,3	—
Commuter	35	35	35	1,2,3	—
Freight	104	104	35	1,2,3	—

The following graphs present the results of simulations for 5 cases under allowances, being one type of allowance tested at a time.





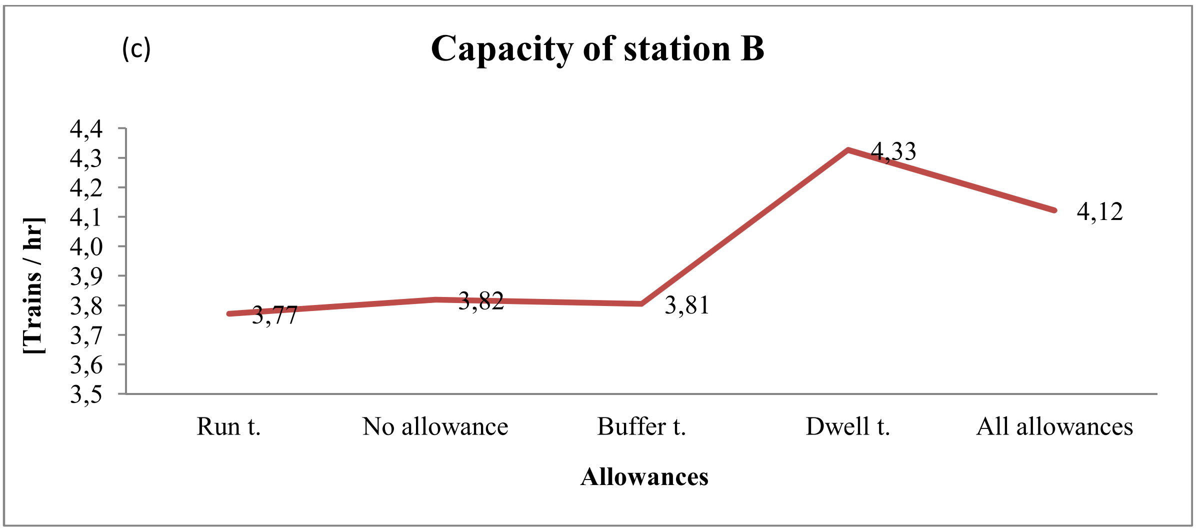


Fig.19 (a) Delays per train. (b) Extended dwell time. (c) Capacity at station B.

As can be seen from the delay distribution graph, runtime allowance gives rise to higher departure and arrival delays at the station. This is due to the fact that the running time allowance is already lost on the line before the trains arrive at the station. This is disadvantage of running time as compared to the dwell time allowance where all amount of the allowance can be used to recover the lateness after the train arrives at the station. The dwell time scenario in this case gives the smallest delays in arrival and departure at station B. Moreover, the difference of the departure and arrival delays which is the delay development at the station is smallest as compared with the other allowances. This is mainly the effect of dwell time allowances supplemented at adjacent stations A and C which contribute in reduction of the travel time. The normal and buffer time scenarios show up approximately the same values in their departure and arrival delays. The allocated buffer time between trains, and runtime allowances in this case do not improve the punctuality of trains.

From the extended dwell time graph it is apparent that buffer time does have no role in reducing the extra dwelling time at station B since it is maintained at stations A and C. Runtime allowance moderately affect the extended dwell time at station B by absorbing the delay propagation on the line and avoiding extra dwelling of train when arriving next station and minimizing waiting time other trains which already arrived at station. In the case of this scenario, because of runtime allowance, the average length of extended dwell time per train is improved by 5 seconds (26%) as compared to base line option. Dwell time allowance is ideal in the case of minimization of extended stops since it is purposefully applied at the station to prevent extended dwell time at stations. The combined allowance at a time gives also smallest extension of dwelling of trains. As compared with the baseline alternative length of average extended time is improved by 11 sec. (58%) and 10 sec. (53%) with dwell time and all allowances respectively.

It is obvious that the aim of runtime allowance is to increase reliability by absorbing the occurrence of delay along the line, but lowering the capacity. The line graph of the capacity shows that there is no major difference in capacity outputs among the runtime, base line, and buffer time alternatives. The capacity output of the station is relatively higher for dwell time alternatives compared to the rest alternatives. The dwell time application at stations in this scenario reduces significantly the delay development at station which is one of the components in analytic calculation of capacity, and in this scenario this parameter determines the capacity more than the travelling time. The simulation result shows that there is no noticeable time difference in travelling time in these 5 alternatives. Therefore, this particular experiment indicates that dwell time supplement is vital for capacity improvements in single track stations.

4.2 Scenario 2

4.2.1 Dwell time variation with block section

A station dwell time is one of the important factors controlling the performance of stations, quality of service and reliability. Dwell time is composed of the time elapsation for opening the doors of trains, movement of passengers, closing doors, and waiting for departure after closing the doors.

This alternative is to see the effect of block section sizes between stations on the dwell time of trains arriving and departing at station. It also aims to figure out how the capacity of station is influenced when trains are subjected to elongation of dwell times. The variations of other parameters which control the capacity such as delay developed at stations, travelling time of trains are seen at the same time. As passenger volume at station increases, operators may want to increase the dwell time of trains for boarding and alighting. In this perspective this experiment will also indicate the impact of dwell time increments on capacity of station.

This experiment is done on stations spaced by 20 km , and the number of tracks of station B is double of the first scenario, which is 6 enabling six train to arrive at station. The input setups are shown in the table 6 and this setups are used onwards with other experiments as well.

Table 6 Setups for dwell time variation with block sections

Infrastructural			**Operational**			
			Interclocking [Sec.]		**Trains' speed [Km/hr]**	
Interstation distance	20 km		Setting time	6	Regional	160
Station track size, B	720 m		Release time	6	Commuter	140
Number of tracks , station B	6		Point setting time	6	Freight	90

Size of the block sections between stations are varied from 1 km to 3, 5 km and for each block section the minimum dwell time needed by the signaling system is found. This is done by looking at scheduled time table in RailSys and fixing errors which arise from blockage and conflict of trains that occurs at midway station. For example, as train ready to depart a station may be blocked by another train arriving to the same station. These trains may try to occupy the adjacent block sections to the station at the same time. This conflict is rectified by holding the train at station for longer dwell time until the other trains enters the station.

Under each block size, the variation of dwell time is done by adding a common difference of 20 seconds with initial minimum dwell time of every train in the timetable as shown in the following diagram (*see fig.20*). The time designated as t, is the minimum dwell time a train in the timetable requires for execution of routing.

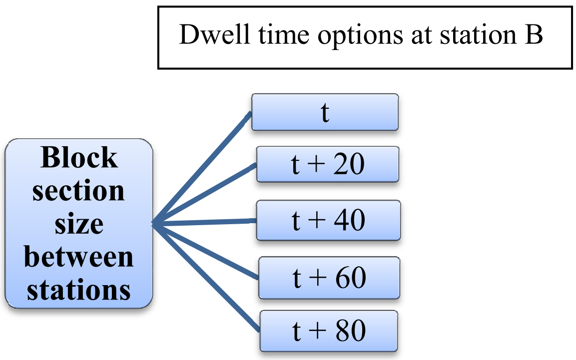


Fig. 20 Dwell time variation under each block section size scenario

Minimum dwell time

In this particular section, the minimum dwell time is the smallest length of time that the signal system requires the trains to stop at the station before the line section is clear and ready for routing, and should not be confused with the 'minimum dwell time' a user may want to keep a train at a station to allocate dwell time allowance during scheduling a timetable.

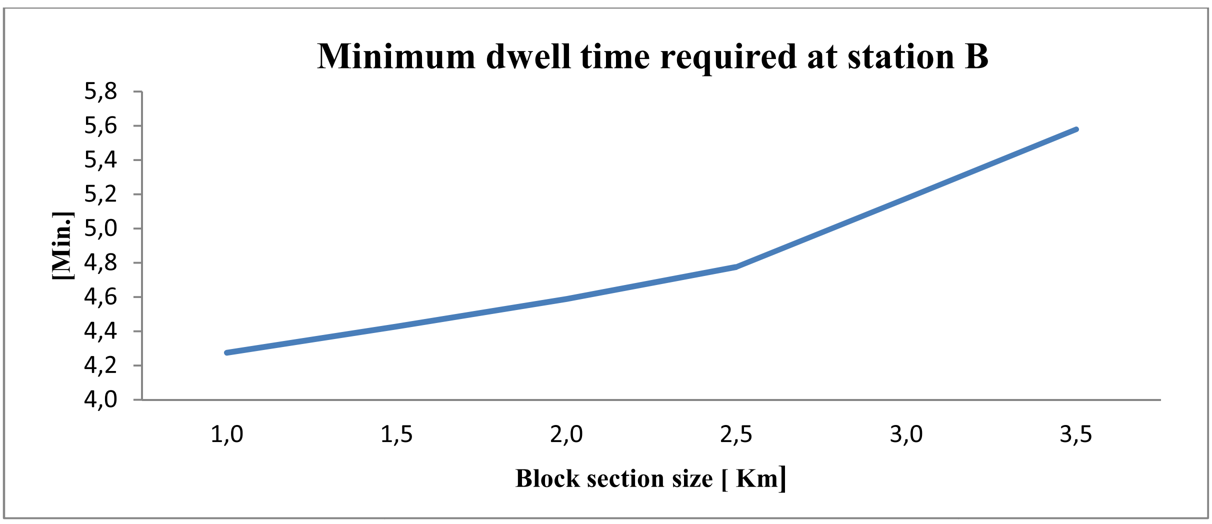


Fig. 21 The minimum dwell time required at station B as block size changes

As can be seen, the increment in the size of the block section induces more dwell time at the middle station. This is due to the fact that longer block section gives wide spacing between trains and longer blocking time which increases the travelling time of trains. The trend of the line is linear and the slope after 2,5 km of block section increases faster. Assuming the overall line to be linear, the slope of the trend can be approximated.

$$\frac{\Delta dwell\ time}{\Delta Block\ section} = 8\ sec./0{,}5\ km, \qquad (R^2 = 94{,}78\%)$$

Distance between station being unchanged, increasing the block section size by 0,5 km would necessarily add average dwell time of 8 seconds on trains stopping at the middle station.

Average lateness development departure

As mentioned previously lateness development departure is the difference between departure lateness and arrival lateness of trains at station which means additional dwell time beyond the scheduled dwell time. It is one of the time components used to calculation of capacity in this paper.

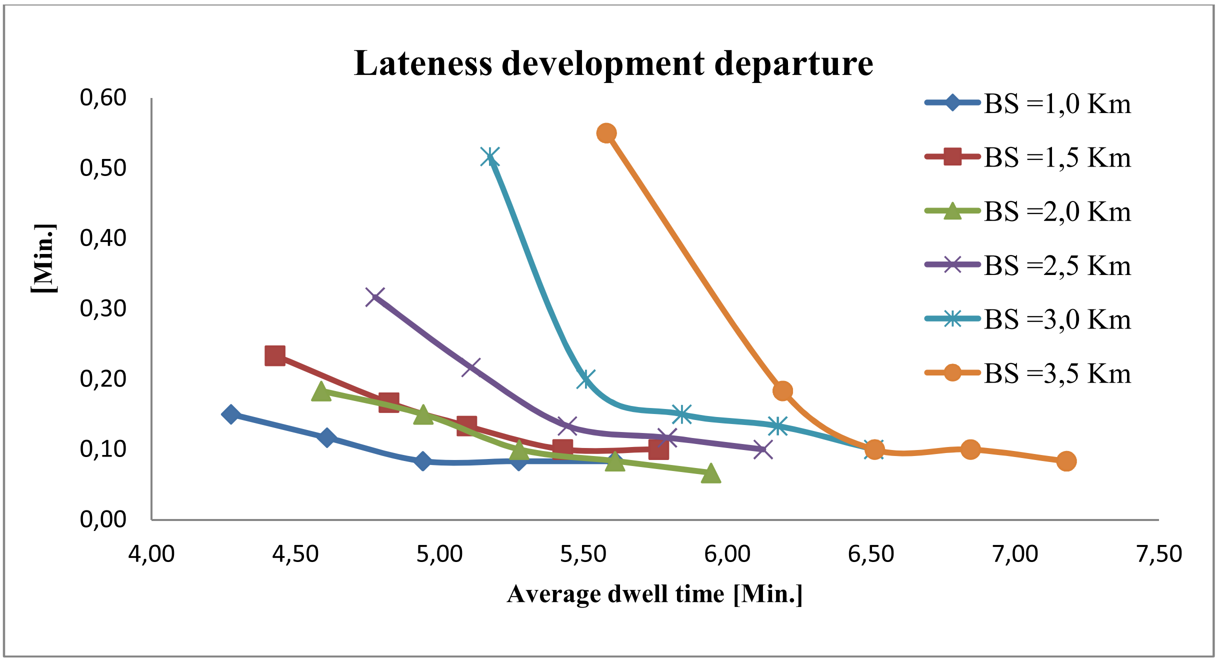


Fig. 22 Lateness development at station B as a function of dwell time and block sections

Increment in dwell time results in reducing lateness development departure of trains. Block section wise, the minimum or initial dwell time required by the system as could be seen before increases with block section size, and further supplement to dwell time for each block section would decrease lateness development. Generally as the block section size between stations increases the lateness development also increases.

Capacity

Fig. 23 shows that increasing block section sizes in between stations and dwell time at station would reduce number of trains through the station. As the block section length increases the blocking time, i.e. the time when a block section is occupied by a train, will also increase which contribute increment of travelling time between the stations and thus, capacity reduces. It is quite apparent that increasing dwell time, as one of the time components of capacity, directly decreases the number of trains since it has inverse relationship with capacity. However as block section grows bigger, in this case 3 km and 3, 5 km, increment of dwell time, unlike the smaller block section sizes, shows a trend of increasing the capacity to a peak value for a certain optimum length of dwell time in hyperbolic manner and decreases afterwards.

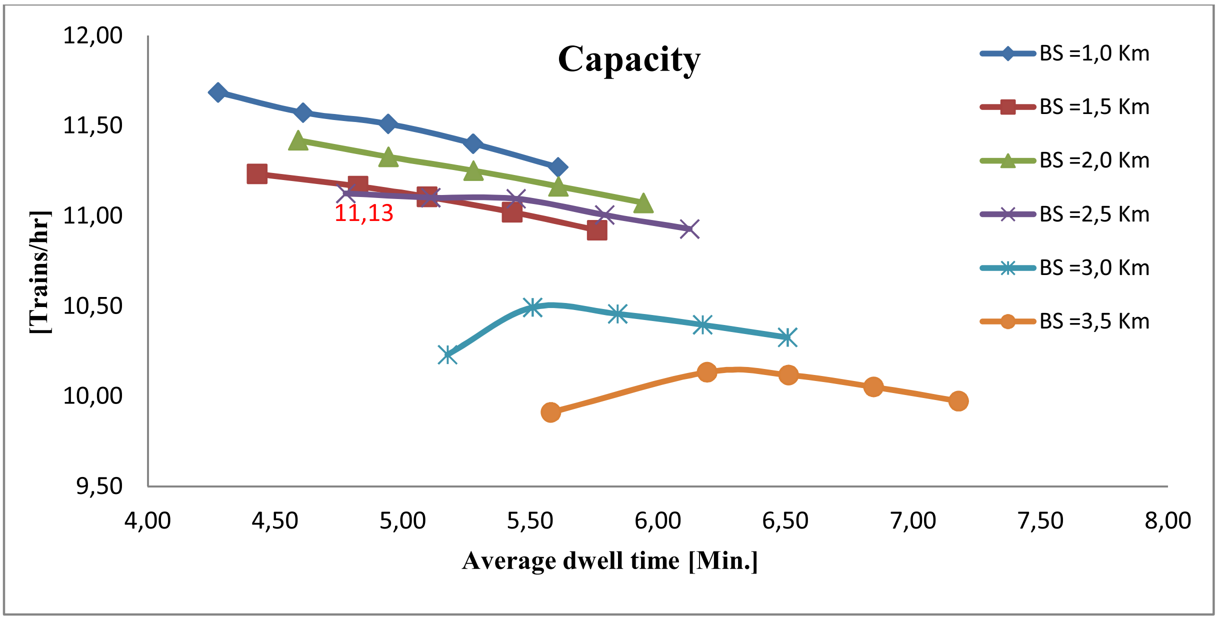


Fig. 23 Capacity variations at station B as function of dwell time and block section

4.2.2 Block section variation with trains speed

This experiment aims to see the variation of block section sizes for different train speeds. Speed of train is the most dominant operational parameter of railway capacity. Slow trains lower the capacity because they consume longer travelling time. Heterogeneity of trains, i.e. proportion of each type of train and difference in speed are other factors that reduce capacity.

As heterogeneity and speed difference increases the time gap irregularity occurs in between departures.

The size of block section in which the trains run can affect their speed performance. It also determines the spacing of the trains along the line. Especially block section adjacent to station has effect on entry time of trains following after the first train has entered.

The maximum running speed of trains are varied to 4 different alternative by reducing 20 km/hr from the maximum allowable speed of regional and commuter trains, and 10 km/hr from freight train. The average speed of the trains in each alternative is used to designate respective alternatives and is weighted by train composition as shown in table 7.*(See Appendix B7 for calculation of weighted average).*

Table 7 shows the four alternatives for speed variation of trains. Any other operational and infrastructural parameters held unchanged. In all alternative trains' accelerating and braking capability are the same. The combined effect of block section size and speed of trains is studied.

Table 7 Speed variation alternatives

Traffic	**Speed variation [Km/hr]**				**Composition of trains**
	Alternative 1	**Alternative 2**	**Alternative 3**	**Alternative 4**	
Regional	100	120	140	160	16,70%
Commuter	80	100	120	140	66,70%
Freight	60	70	80	90	16,70%
Speed(cummulative)	**80**	**98**	**117**	**135**	

Trains contained in each speed alternative are simulated over the modeled infrastructure with 6 different block section sizes between stations as illustrated in the following figure.

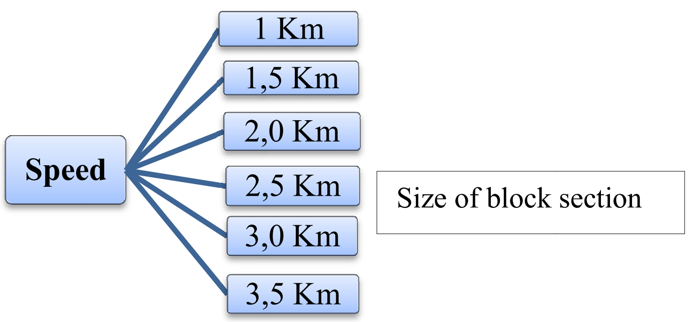


Fig. 24 Block section alternative under speed scenario

The two major components in analytical approach of capacity used in this paper, travelling time and dwell times are seen in this subsection.

As can be seen from the following diagram there is a general trend of increment in travelling time as size of block section increases for each speed alternative. If we linearly approximate the travelling time, 250 % increment of block section size in between the station, would raise the travelling time by 5 to 13 %.

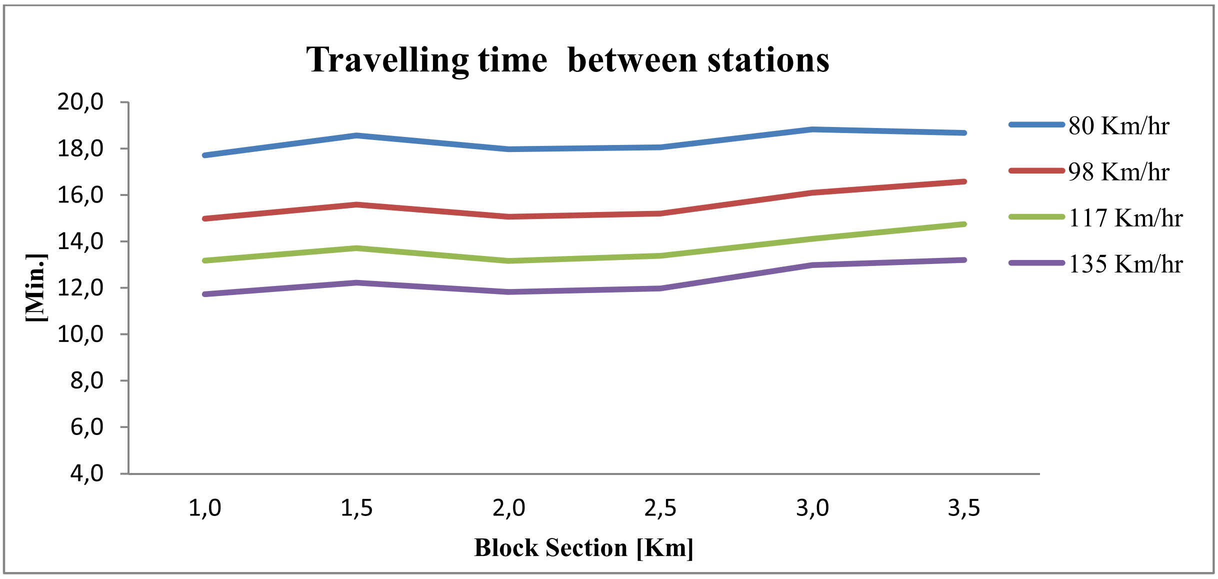


Fig. 25 Average travelling time between station B and A or C

We can also see that as the average speed increases the difference between travelling time among speed curves gets smaller for each block section, which means the saving in travelling time because of speed increments gets lower. This is due to the fact that increase of speed of trains requires longer breaking time to stop at signal and stations. This is also pointed out in [4].

The scheduled dwell time is calculated according to the signaling system which fixes how much time a train should stop at the middle station based on the circumstances in the station i.e. according to the presence of trains going out and coming in of the station. This is done manually by shortening the dwell time of trains at station which gives conflict between trains in the graphical timetable and by looking at the error log in the RailSys; the conflict is fixed by extending the dwell time.

In the timetable there are 12 trains from each direction. The average scheduled dwell time is the mean of the scheduled dwell time of all 24 trains. This average value is calculated for every block section size considered.

From *fig. 26*, it is quite apparent that as the trains' speed increase the dwell time requirement at station decreases. This is because when trains run faster those trains already at station do not experience long stopping time in waiting for the other trains coming to dwell.

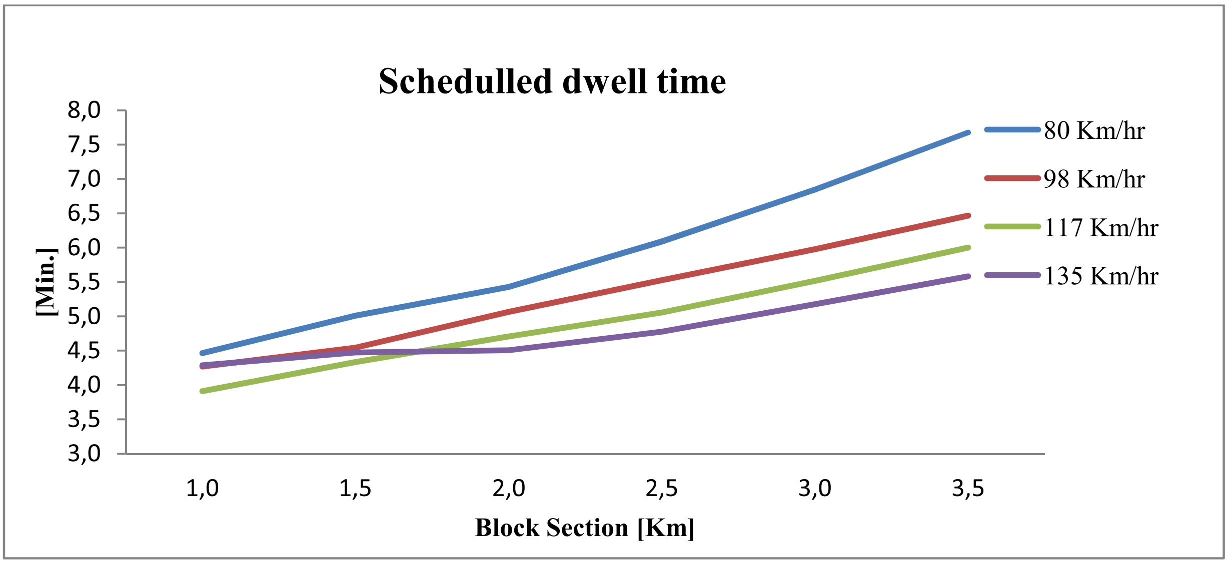


Fig. 26 Variation of scheduled dwell time at station B with speed and block section

Both average scheduled dwell time and travelling time increase as the block section increases. If we estimate with linear trend line for both of them the slope of dwell time is bigger than the slope of the travelling time. This means that for increment in size of block section, station dwell time is more sensitive than travelling time.

Table 8 Comparison between slopes of average travelling time and dwell time for speed alternatives

Average Speed km/hr	Slope of estimated line for travelling time (min/Km)	Slope of estimated line for scheduled dwell time (min/Km)	Difference
80	0,05	0,72	0,67
98	0,11	0,51	0,40
117	0,12	0,53	0,41
135	0,13	0,30	0,17
Average	**0,10**	**0,52**	**0,41**

Therefore, on average the dwell time increases 0, 41 min/km more than the travelling time.

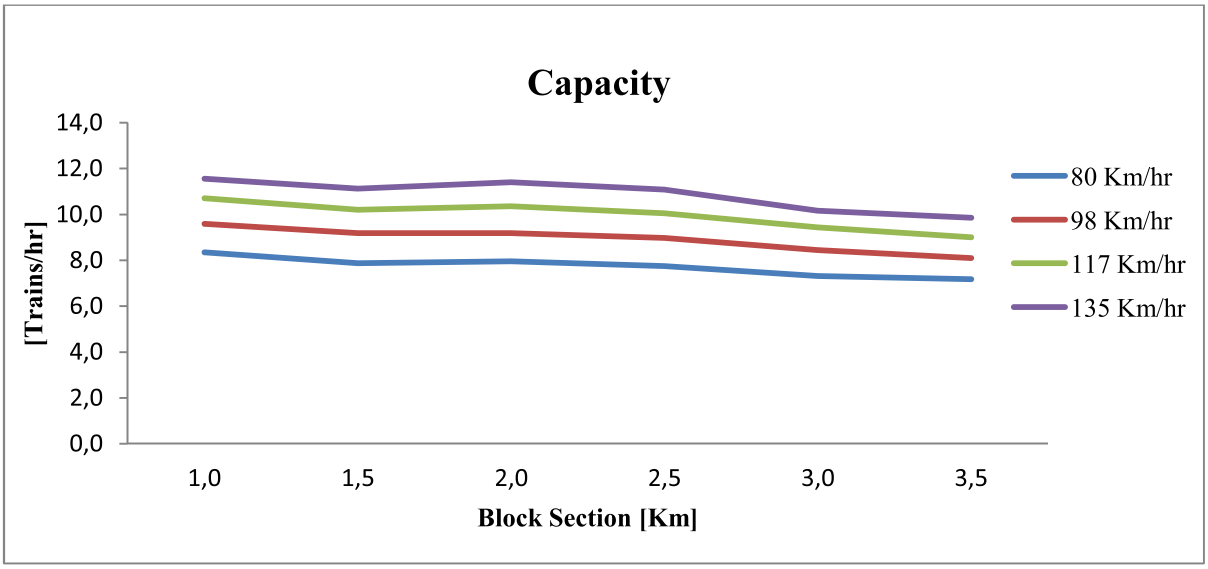


Fig. 27 Capacity at station B as function of speed and block section sizes

As the block section size increases for a given speed, blocking time increases, headway between trains generally increases. 'Particularly for very low speed, as the block section increases the headway time increases more sharply than for high speed because of consumption of time of a train by travelling longer block section, then after which the second train will follow. The travelling time is greater than the breaking time,' M. Abril et. al [4, p.799]. With the same analysis, when the speed is high, the travelling time is less than the breaking time, which shows less significance of travelling time than breaking time. If we see the other component of capacity which is the dwell time at station B, for each speed there is fast increase in scheduled dwell time, than the rate travelling time increases.

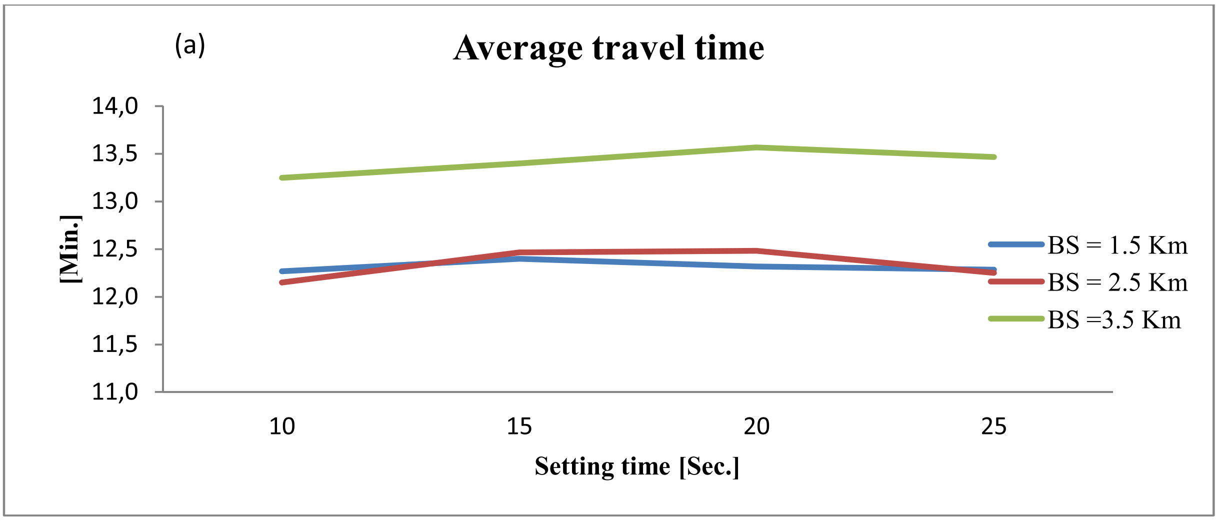
4.2.3 Setting time variation with block section

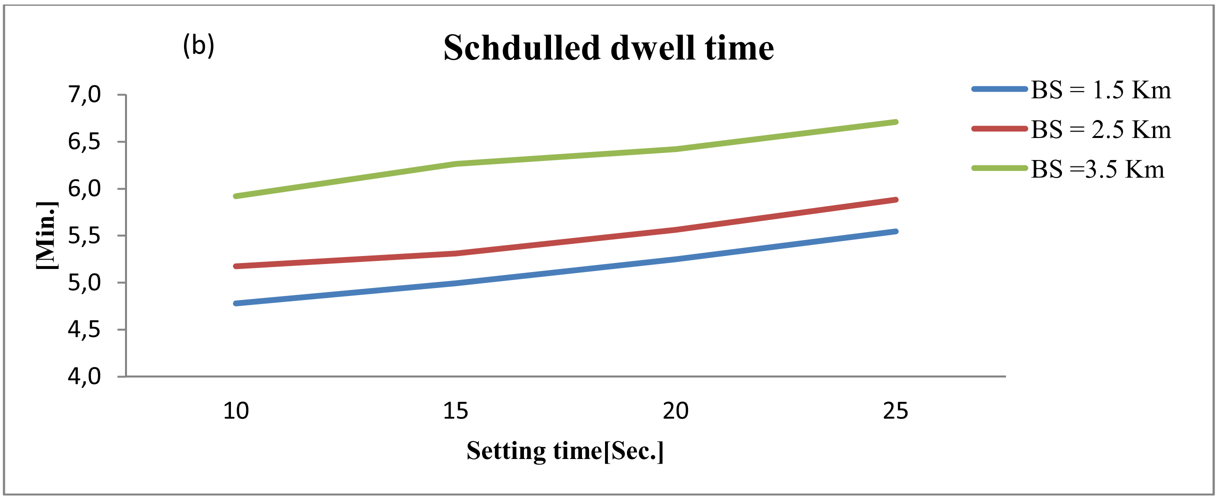
Setting time is one component of blocking time - total occupational time that a train spends for one block section for which a train is identified to engage part of the section where others trains are not allowed to occupy for some time. Setting time depends on the signaling system used and takes link attributes specified during infrastructural set ups. For example if the block section composed of different maximum allowable link speeds for trains, then the signaling system considers the minimum of these maximum speeds as the train runs with in the block section, as described in [9]. Blocking or occupation time of a single block section from stair case diagram of a train is shown in *fig.7.*

Time of 10 sec. of initial reference for setting time is used and varied to 25 seconds for the default interlocking type in RailSys against three different sizes of block section: 1,5 km ;2,5 km; 3,5 km. The trend line is studied for number of trains, travelling time, and dwell time at the station under consideration.

Travelling time

The elongation of setting time does not greatly affect the travelling time of trains. This means that there is enough distance gaps between the trains due to significant speed differences. As a result, the interlocking does not restrict speed of trains or stop following trains when new route is set up behind a passing train. Therefore the new route setting process by the interlocking takes place in time before the trains approaches the main signal, so trains do not reduce their speed or come to stand by because of route setting process.





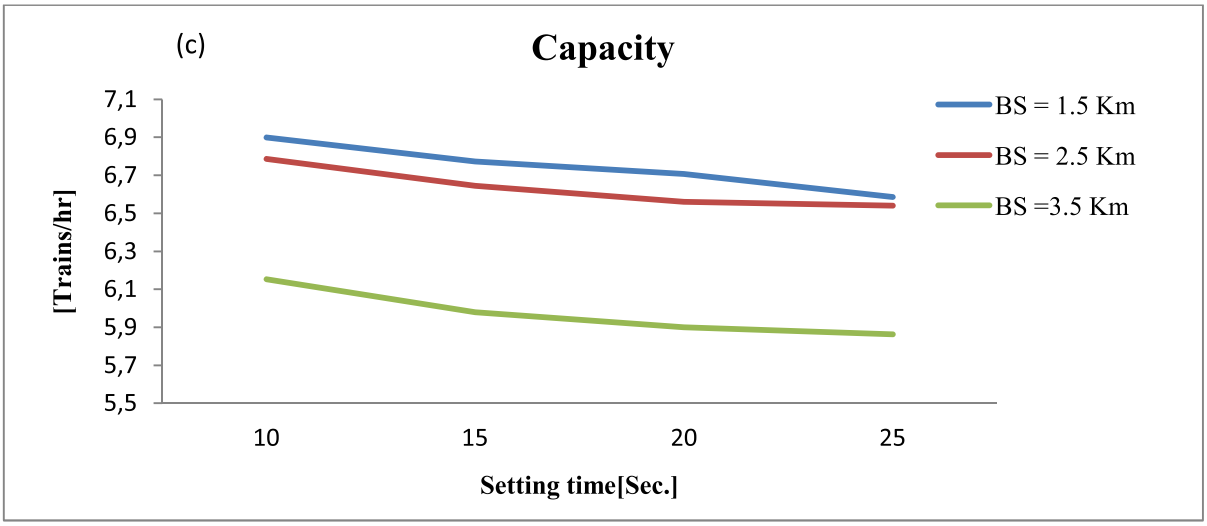


Fig. 28 (a) Variation of Average travel time. (b) Scheduled dwell time. (c) Capacity at station B as function of setting time and block section sizes

Dwell time

The scheduled dwell times like previous experiments are set based on how much time a train should stay at a midway station in order to avoid any conflict with any other trains entering or leaving the station. Therefore it is based on the requirement of the signaling system and trains operational parameters such as allowable speed with in station area and acceleration. In this experiment station dwell time increases directly with setting time. The route setting process for departure of trains from the mid station starts after all the trains dwelled for their scheduled time and there are 3 trains in each direction. Since this is single track, there are overlaps of routes for trains departing to the same direction as they should pass through one common merging point at the end of the station. This process elongates the dwell time of the trains. Heterogeneity of trains and presence of perturbation makes train arrival to station irregularly and those trains arriving at station would stop for extended length of time, and as the route setting time rises, it would aggravates the length dwell time at the station. So, in this particular experiment route setting time has more impact on dwell time with in station area than on travelling time between stations.

It can be concluded that smaller block section between adjacent stations and smaller setting time in interlocking gives good capacity at the station.

Arrival delay

Arrival delay of trains at a station can be one indicator for reliability. Reliability is the ability of an item to perform a required function, under a given environmental and operational condition and for a stated period of time (ISO 1994). Arrival delay is a measure of punctuality which is in turn a measure of reliability of railway operation [10]. Punctuality is defined as percentage of trains that arrive at station in less than some fixed time of delay. In this paper, 6 minutes is considered for evaluation of trains' punctuality.

Due to differences in speeds (heterogeneity of trains), and minimum headway between the trains, perturbation can easily propagate among them. It is apparent that the arrival delay for longer block section is higher because it increases the blocking time. Setting time does not affect the travelling time a lot, and thus the arrival delay. For block section of 2,5 km it increases until 20 second and falls down, but for 1,5 and 3,5 km it does not increase significantly. We can say that lower block section is reliable for punctuality of trains at station.

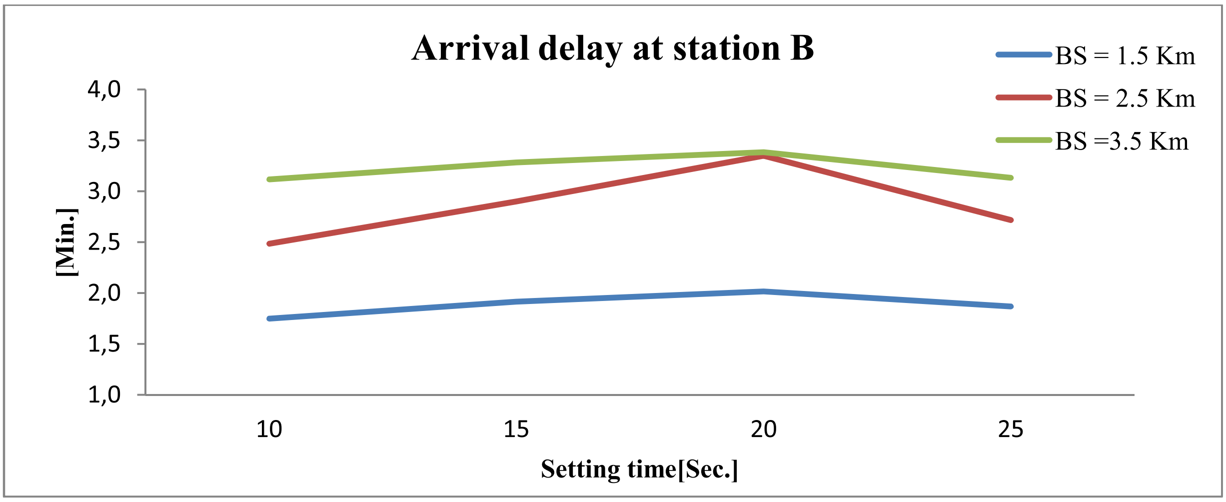


Fig. 29 Arrival delay at station B as a function of setting time and block section sizes

4.2.4 Release time variation with trains Speed

The impact of the combination of release time and speed of trains on number of train passage in station is seen in this part of the experiment. Release time is the last component of blocking time which the interlocking has to wait after the end of occupying train passes over the release contact, in order to open the section for following train. As can be seen from the following diagram, the average travelling time of trains is not affected as the release time is increased.

This is owing to the significant speed difference between trains that elongated release time does not create delays or stoppage of trains to enter a new block section. It is straight forward that the higher the speed is the shorter the travelling time and the greater is the capacity. There is a slight trend of increment of dwell time as the release time increases but not significant. *See fig. 30 (b)*

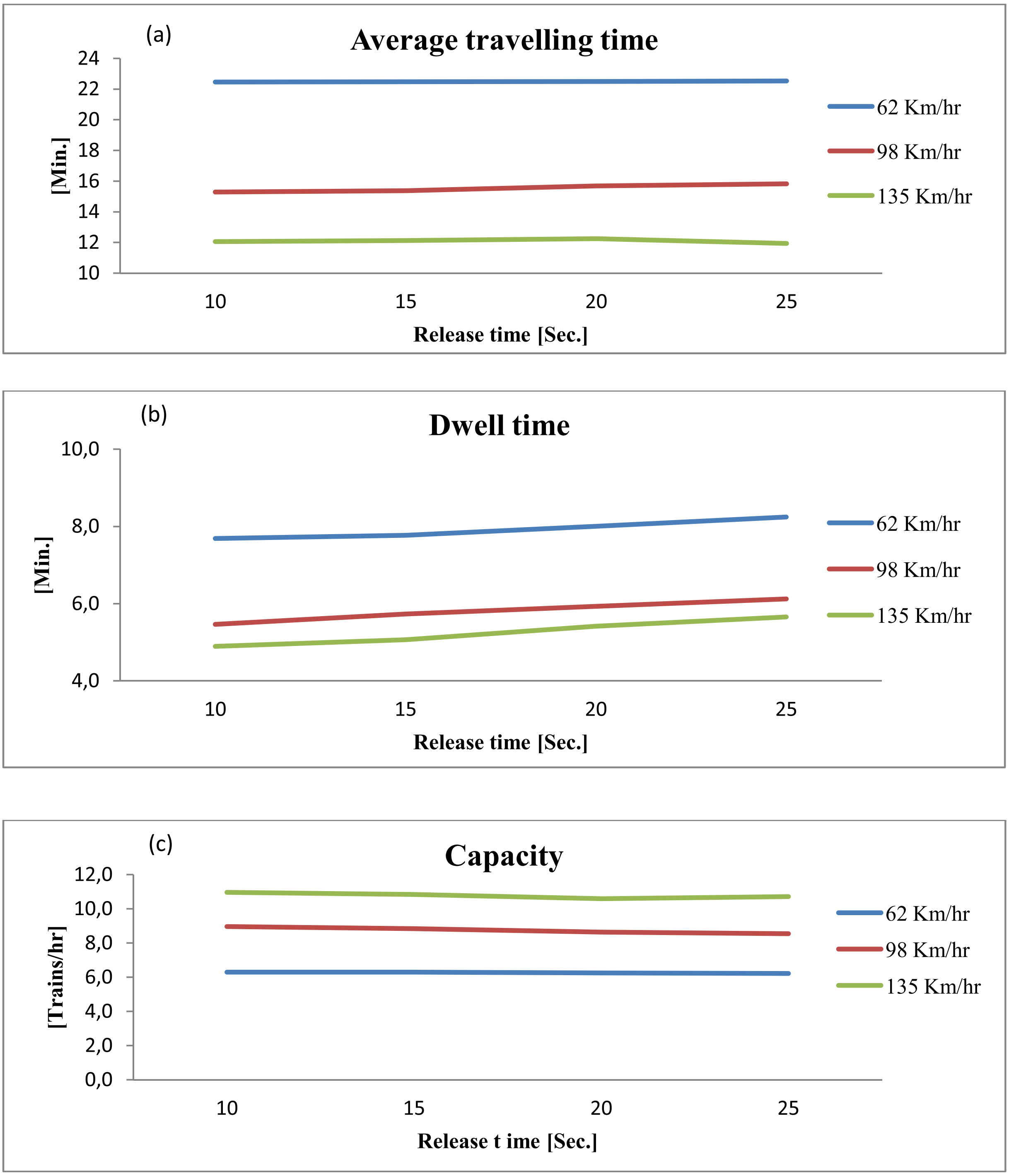


Fig.30 (a)Variation of travelling time between stations.(b) Dwell time requirement at station B. (c) Capacity as function of release time and speed.

The arrival lateness at station B is shown in the *fig.31*. Even if higher train speeds could give us shorter travelling time, there is observable arrival delay when trains attain higher speeds. Higher speed of trains is prone to the effect of perturbation and propagation of knock on or secondary delays. The other reason, there is possibility of departure delay at the end stations.

Trains with average running speed of 63 km/hr do not suffer from arrival delay with increment of release time. The individual train type has lower speed and the impact of perturbation is easily absorbed in the headway gap between the trains.

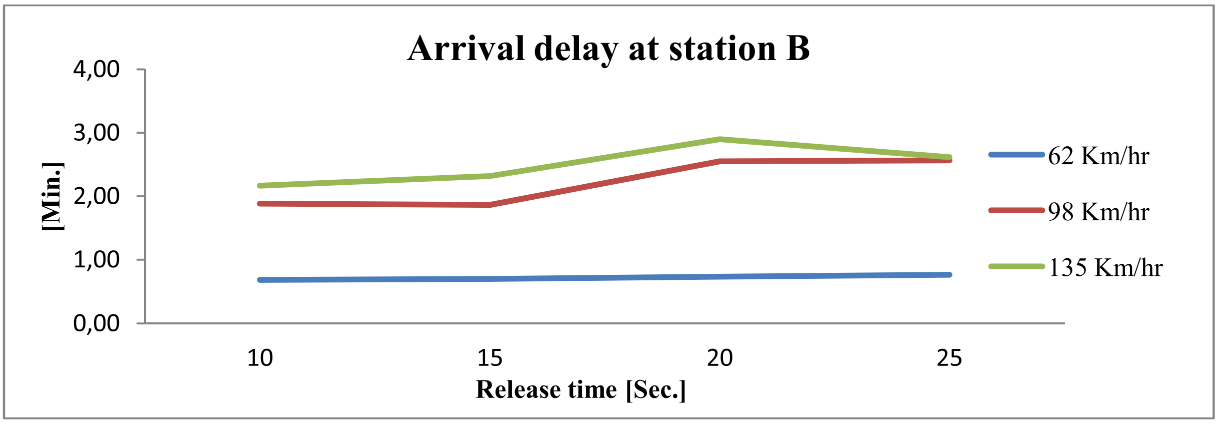


Fig. 31 Variation of Lateness in arrival as a function of release time and speed.

4.2.5 Perturbation variation with trains Speed

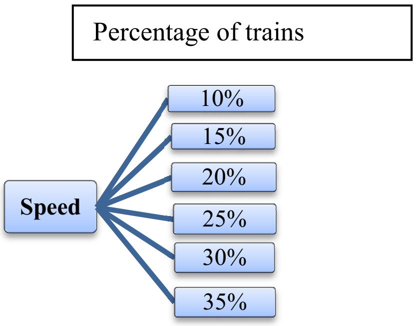
The aim of this section is to quantify the effect of knock on delays on performance of station B as consequence of variation of trains' entry delay at station A and C. Two kinds of variation of perturbation are done:

- Increasing the percentage of trains affected by entry lateness while average lateness and maximum lateness per train are unchanged, i.e. 1 min., and 5 min. respectively.
- Increasing the average entry lateness, while the proportion of perturbed trains and maximum lateness per train are fixed, i.e. 10%, 12 min. respectively.

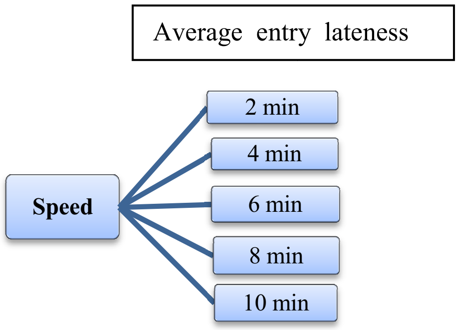
As in the previous scenarios, the perturbation of trains here is also based on negative exponential distribution, and the period of simulation is 120 days.

Three speed scenarios are considered for the trains, which are 50%, 75% and 100% of their maximum speeds. For instance, in 50% V_{max} scenario, every train is scheduled to run at half of its maximum speed.

The layout of the variation is illustrated in *fig 32*. The variation is applied on scheduled timetable 2 whose specification is indicated in *Table 6*.



(a)



(b)

Fig. 32 Layouts for variation speed with percent of perturbed trains(a), and average entry lateness (b)

Results of variation in percentage of trains perturbed and speed of trains

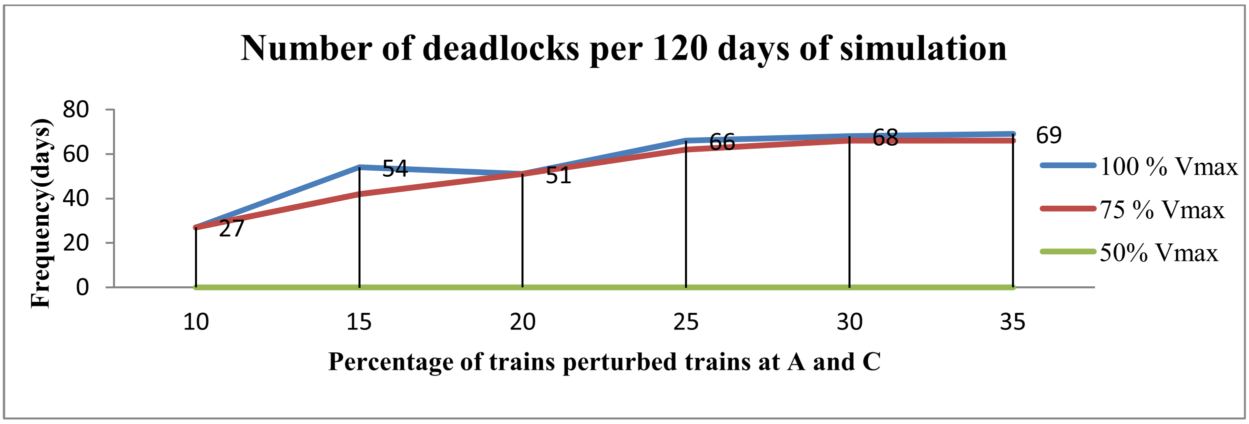


Fig.33 Number of deadlocks in the system

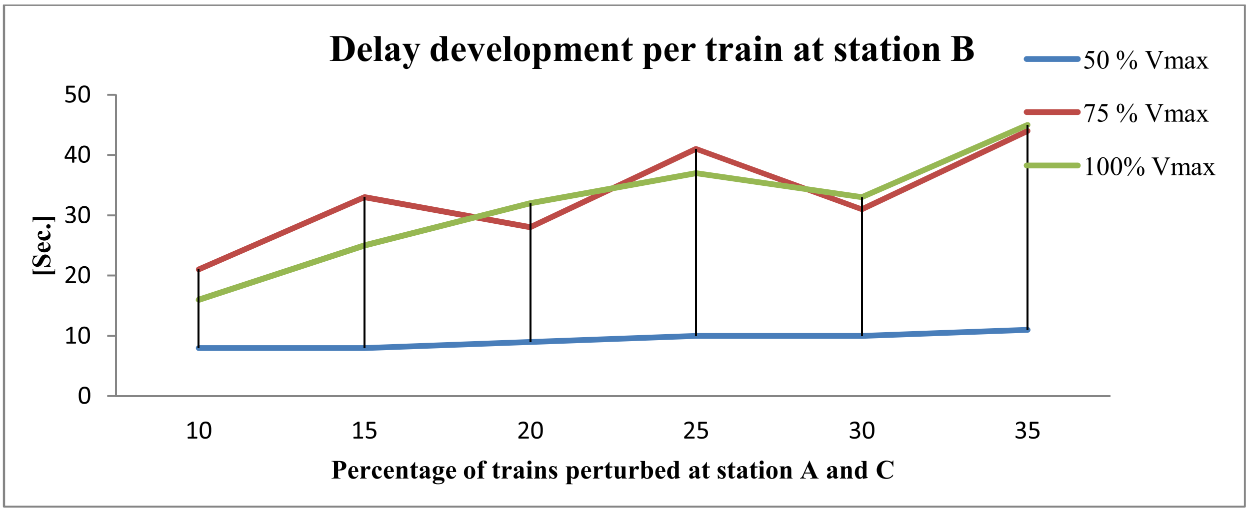


Fig.34 Delays development at station B

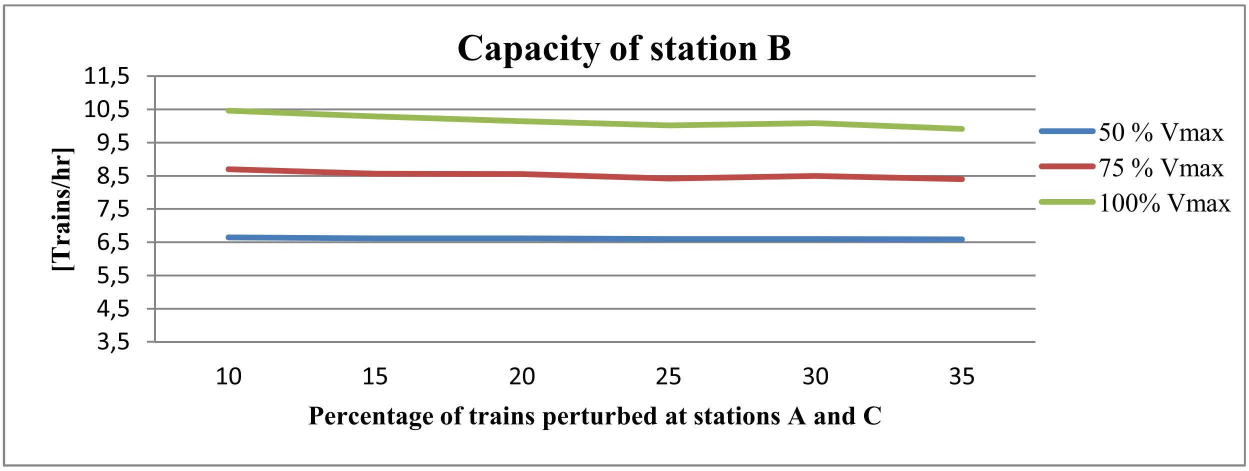


Fig.35 Capacity of station B

As can be seen from the results in Fig. 33, deadlocks increases with higher trains speed and percentage of perturbation. The same holds with delay development at station but more stable with 50%V_{max}. Capacity is mainly dominated by the speed of train than perturbation, but there is slight trend of declining for 100%V_{max} for higher percentage of perturbation, indicating that relatively higher speed of operation is prone to loss of capacity because of higher magnitude of disturbance. One reason is the growth of delays developed at station, which is a component parameter in the equation of capacity with inverse relation. The general parallel trends of capacity curve is because of the direct relationship between speed and travel time which increases the capacity. It is apparent that the effect of perturbation on travelling time is insignificant as the application of perturbation is imposed on trains at station A and C, which induces only arrival delays at station B. Its effect on train's speed between stations is not significant and the travelling time is not affected.

Deadlocks are highly linked with speed of trains in this scenario. As stated in section 4.1.3, trains undergoing entry delays are the causes for deadlock between two trains on the line. Here, it is realistic that the frequency of deadlocks is aggravated with increment of both speed and number of trains perturbed at end stations, but the timetable scheduled when trains run at half of their maximum speed is found to be so robust that entry delay at station A and C could not initiate any conflict between trains, and no deadlock has occurred. *See fig. 33*

The experiments done for variation of average entry delay showed up quite similar results in capacity and number of dead lock found in the variation in percentage of trains perturbed. The delay development, however, in later case, grows for lower speed of trains as shown in *fig 36*.

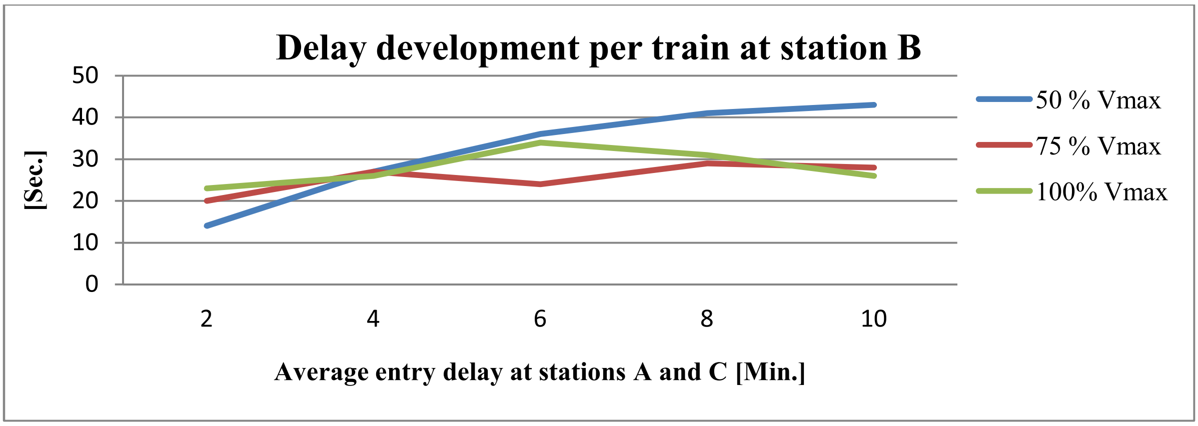


Fig. 36 Delay development at station B rises with higher average entry delay & lower speed.

4.3 General comparisons

The two timetables are examined with respect to different instances and considerations. The main basic difference between the timetables is the addition of 3 more tracks in the infrastructure setup of middle station in the case of second timetable, which allows us to increase number of train departures from the outside stations. Since increasing trains in the timetable usually aggravate the propagation of secondary delay, for balancing this it was considered 10% of trains are to have entry delay at outside stations while 20% was assumed for the first timetable. Secondly, single parametric study takes place in the first scenario where as in the second scenario two parameters are combined for analysis. In both scenarios trains do have the same stopping pattern. Also, their speed performances, breaking and accelerating capabilities are constant.

4.3.1 Comparison of significance of variables

Among the parameters considered under timetable 1, inter-station distance and application of allowances in the timetables have been most dominating factors to the output capacity. Inter-station distance in particular is seen to affect capacity greatly since it has direct impact on travelling time of trains. Among the alternative allowances tested in the first timetable, dwell time allowance showed up the least arrival and departure delays and thus with the maximum capacity output. Block sections variations are considered in both scenarios. It was observed that these divisions of the block length into many segments have negligible influence on capacity in the first scenario since the entire block length is engaged with only a single train at a time. Size variation of block section in the second scenarios has rather produced considerable effect in capacity because in the second scenario successive trains are scheduled to depart one after the other in the timetable where the block sections actually affect their spacing.

4.3.2 Capacity between the two timetables

The two general scenarios have differences in infrastructural setups in station B which consequently gives different timetables. Further parameters considered under these timetables have different influences on capacity which make them difficult to put comparison among them. However, the main differentiating factor between the two timetables is the number of tracks at station B and therefore general comparison can be made by selecting two representative alternatives from each scenario which have relative similarities in some of physical dimensions.

It is easy to consider capacities in section 4.1.3 and 4.2.1 with respect to the following selected inputs. *(See Table 9)*

Table 9 Comparison of capacity between timetable 1 and 2.

Category	Parameters	Timetable 1	Timetable 2
Infrastructure	Number of tracks of station B	3	6
	Size of station B	400 m	720 m
	Number of tracks stations A and C	3	3
	Size of stations A and C	1750 m	1750 m
	Station to station distance	20 km	20 km

Signaling system (ATCS)	Block section size	2,5 km	2,5 km
	Interlocking setting time	5 sec	6 sec
	Interlocking release time	5 sec	6 sec
Services	Composition [Reg., Com. and Fre.]	20% ,60%, 20%	17%,66%,17%
	Speed [Reg. Com. and Fre.]	160,140,90 Km/hr	160,140,90 Km/hr
	Capacity of station B	**3,5 trains/hr**	**11,23 trains/hr**

From the above table, we can see that significant increase in capacity of station is achieved by doubling the number of tracks in the station. The increment of capacity is more than three folds. The values of capacities are taken from representative scenarios for the timetables. *(see fig. 13 and fig.23).* So, increasing side tracks in a station is obviously one of possible ways of increasing capacity. This paper has aimed to investigate the capacity of a single station without affecting sizes and setups of outer or adjacent stations. In order to increase the capacity output of an overall single track line, however all stations along it have to have increased number of tracks.

Comparison of delay developed at station between the representative scenarios

The presence of deadlocks in case of section 4.1.3 for inter-station distances of less than 20 km had great influence on the arrival of trains. At 20km of inter-station distance where comparison is done with section 4.2.1, the developed average delay of trains at station is the lowest. In section 4.2.1 also, if we see delays with respect to block section of 2, 5 km, it reduces with increments of dwell time at stations. So, roughly in the view of punctuality in arrival and departure the two nominated sections are comparably good.

4.3.2 Costs of construction between single and double tracks

Costs of construction of railway track per unit length widely varies based on structures required and speed of operation. For the simplified single track model considered in this paper, costs for conventional ballasted track for a speed of 200 km/hr is assumed. Doubling the track line would increase the capacity up to four times [4], but it costs lot of capital. While building double track is not always wise way to increase capacity, the feasibility of a given project is still determined by demand in passenger or freight traffic. Since this paper studies capacity entirely within simulation program for hypothetical line, it cannot consider cost benefit analysis. *Table 10* indicates construction costs of single and double tracks lines based on recent information collected from the Swedish transport administration, Network Rail and Korean railways.

Table 10 Infrastructural costs of construction for single/double track line, MSEK/Km

Cost	Earth work	Track	Bridge/viaduct	Tunnel
Cost(most likely)	21	5	188.5	365
Min Cost	16.8	4	160	320
Max Cost	30.6	7.6	255	510
Cost for double track (%)	120	160	160	130

Source: KTH - Division of Highway and Railway Engineering

Cost comparisons of the two scenarios

As in indicated above the capacity gain because of increasing the tracks at station is remarkable. It may be important to compare these two scenarios with their estimated cost of construction. Cost estimation is based on the data provided in Table 10, but cost of land acquisition and environmental impacts are not included since this is not a real project. With the similar argument, this part does not intend to calculate changes in delay costs. This is due to lack of passenger demand though arrival and departure delays of trains are readily available from simulations. (Cost calculations of stations and tracks are indicated for both timetable scenarios in tables in Appendix D). The purpose of the calculation is therefore to help us to evaluate the tradeoff between capacity and cost and use them to put comparison between the two scenarios. This method may in general provide aid to capacity planners in decision making while selection among alternatives for final project, or comparing different capacity gains and costs incurred in modification of exiting railway tracks such as upgrading or adding sidings to single track line for crossing of faster trains.

Table11 Estimated cost of construction for scenario 1 and 2

	Scenario 1	Scenario 2
Construction cost of station and tracks [MSEK]	1814	1890
Capacity of A – B – C [Trains/hr]	3,5	11,23
Cost /Capacity [MSEK/Train/hr]	518	168

From the above table it is evident that investing as low as 4,2 % in tracks in station B would raise the capacity as much by 221 % (in scenario 2). Cost per capacity unit is higher for scenario 1 than that of scenario 2 indicating that inexpensive modification of infrastructure gives up significant change in capacity. That means investment on more tracks in the stations becomes competitive cost wise as seen from the capacity gained as result of it.

5. DISCUSSION AND CONCLUSION

5.1 Discussion

The sections under first scenario consider the effect of single parameters on capacity. Section 4.1.1/2 studies the relationship between the block section size and capacity of the mid station. In the timetable development only one train scheduled to run between stations and decreasing the block section size (by increasing the number of block divisions), capacity is not affected significantly due to the fact that the performances of the trains i.e. speeding or breaking is not changed with the variation of length of block sections. As a result the travel time is not altered to a degree that improves the capacity considerably.

In section 4.1.3, it is indicated that the average travelling time increases linearly for the distance range under consideration (15 -55 km). In these variations, the presence of deadlocks in the timetable for inter-station distances shorter than 20 km lowers the capacity of the station. Even if large inter-station distances lower the number of routings through a station, the arrival delays (punctuality), and extended stops of trains at studied station gets considerable improvements in the timetable of respective inter-station distances. The trend of capacity in the case of section 4.1.4 where the station track size is varied, analogously to inter-station distance, capacity goes down.

The effects of allowances on punctuality of trains and capacity at station B have been seen in section 4.1.5. Dwell time allowance is found to be best parameter in increasing the performance of station and minimize the delays development by the trains at station. The application of buffer time at end station does not minimize delays as compared to the base line alternative where no allowances have been applied to the timetable. Likewise, run time allowance induces highest departure and arrival delays at station due to the fact that it is consumed by trains on the line before arriving at the station.

Sections 4.2.1 combines the block section size between stations, and dwell time at the mid station and see how the capacity changes with their variations. Noticeable change of capacity is observed with both variations. Capacity falls with increments of dwell time in approximately linearly manner for smaller block sections (1- 2,5 km). With longer block sections (3 - 3,5 km); however, it has a trend of increasing and decreasing in hyperbolic fashion. It is also observed that the signaling system requires more dwell time for trains at the mid station as the consequence of increasing size of block sections. This induces lateness development on departure as is illustrated by *fig.22*. The same trend of dwell time is seen in section 4.2.2, where block section size is considered with different speed combination of trains(alternatives). Both travelling time between the stations and scheduled dwell time requirement at mid station increases as block section size grows from 1 km - 3, 5 km. From the results shown in *fig.25*, it is obvious that as the average speed of operation increases the time saving in travelling time reduces as we see vertically for each block section. The same holds true for capacity of station.

The impacts of two components of interlocking time are dealt in section 4.2.3/4. The variation of setting time is seen to bring no big change in the travelling time of trains. Since there is speed difference between the trains which can create enough distance separation among them, the speed performance of following train is not affected by the interlocking process of a passing train (train a head). The scheduled dwell time of trains at the mid station, which is set up in scheduled timetable depending on minimum requirement of signaling system, is rather sensitive with route setting time due to the existence of common adjacent routes for departure of trains with in mid station .The increase of the route setting time has increased the dwell time which in turn lowers slightly the capacity of station as illustrated in *fig. 25(c)*.

In the scenario which combines speed of trains and release time of interlocking, capacity of the station is seen to be actually insensitive with the release time, for the same reason mentioned above, i.e. the enough gaps between the trains along the line as consequence of their speed difference. For three average speeds considered the capacity lines are nearly constant. The lines also indicate vertically that higher capacity for higher average speed.

5.2 Conclusion

In this paper, many alternatives of operational and infrastructural models have been experimented in simulation and analyzed for capacity output. The modeling in the simulation environment has incorporated acceptable infrastructural and operational scenarios with logical assumptions. The modeled signaling system – ATCS-2 approximated the reality in Swedish train operation. Use of simulation output in analytical calculation of capacity makes the results more realistic. One instance can be the actual travelling time of trains in simulation which is the main determinant of capacity. The magnitude of this parameter after simulations is greater than that of in scheduled timetable before simulations because the former considers the primary and secondary delays.

The methodology adopted in this paper can be used dependently in projects to examine expected capacity prior to building infrastructures. It is vital especially for railway projects in places where train operation is starting, where there is no timetable and experience of operation exist to estimate new capacities.

Dealing with capacity of stations, we cannot disintegrate the tracks but in the aim of maximizing station capacity, the single track connecting the stations is found to be a bottle neck even though the capacity of the station can be improved by increasing station tracks. The contribution of signaling system in improving the capacity is shadowed by the constraint of the infrastructure. Besides the single track line, the second major cause for low capacity is heterogeneity of the traffic and the speed difference among them. In order to achieve bigger capacity of stations and single tracks, dedicating the line for a most frequent traffic with symmetrical timetable can be one way to maximize capacity. Secondly, train conjugation can be helpful mechanism to increase the capacity which at the same time can reduce the number of trains in the timetable that minimizes the degree of delay propagations by allowing adequate gap between the trains.

The adopted method in this paper has measured capacity of station based on timetables that include mixture of passenger and freight trains. These are analytical results in terms of trains per hour which are predictive for capacity of the infrastructural models. In order to study visibility and implementation of the these models, practical passenger and freight traffic demands are important.

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Appendix A. Capacity calculation for general scenario 2

From equation 3,3, it is found that, average capacity for single train occupying the section between stations,

$$C_{ave.} = \frac{Time\ interval}{Total\ time} = \frac{60}{2t_t + t_d + t_l}$$

However, in this general scenario, we have three trains departing from end station towards the middle station with some headway between them, h_d at departing station as shown Fig. A1. Therefore, it is required to slightly modify the above equation to suit the situation of this time table.

Let average headway between trains be t_h and considering the green train in *fig. A1*, the total time spent by a train between station A and station C will be

$$t = t_h + t_t + t_d + t_l + t_t = 2t_t + t_d + t_l + t_h$$

With the assumption that travelling time from A to B, and B to C is being the same.

Where, t = total travel time, A to C, or C to A minutes that an 'average train' may take

t_t = actual travel time, from station A to station B, minutes

t_d = average dwell time at station B, minutes

t_l = lateness development at station B, minutes

$= t_{ld} - t_{la}$

t_{ld} = lateness departure at station B, minutes

t_{la} = lateness arrival at station B, minutes

At a head way of $t = 2t_t + t_d + t_l + t_h$, three trains would be passing station B, thus, the capacity will be,

$$C_{ave.} = 3x \left\{\frac{Time\ interval}{Total\ time}\right\}$$

$$= \frac{3\ x\ 60}{2t_t + t_d + t_l + t_h} \quad \ldots\ldots\ldots\ldots\ldots\ldots (A.1)$$

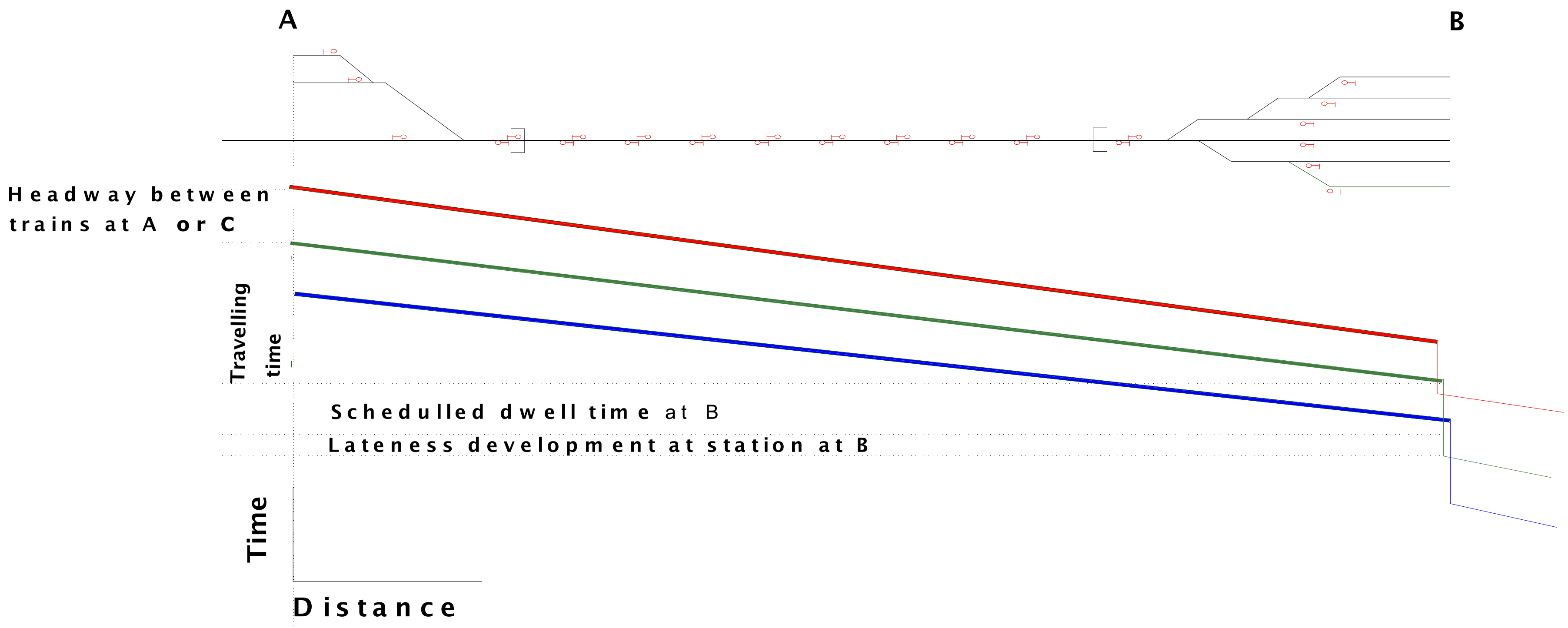

Fig. A1 Trains in timetable II

Appendix B. Input perturbations, simulation outputs and capacity calculations

Appendix B 1

<u>Evaluation 4.1.1: Variation of number of block sections</u>

Entry delay perturbation

		Perturbation inputs			Amount of lateness		
Perturbation location	Total trains	%	Average delay [Min.]	Maximum delay	# Perturbed trains	Total [Min.]	Per train [Min.]
Station A	1800	20%	1	5	335	333,43	0,19
Station C	1800	20%	1	5	355	376,95	0,21

Table of simulation output and capacity calculation

Number of blocksection	Lateness development departure [Min.]	Scheduled dwell time [Min.]	Actual travel time A to B [Min.]	Actual travel time C to B[Min.]	Total travel time A to C [Min.]	Total travel time C to A [Min.]	Capacity [Trains/hr]	Punctuality [%]
5	1,23	0,78	12,72	12,70	**27,45**	**27,41**	**4,37**	95,00
10	1,27	0,78	12,70	12,62	**27,45**	**27,28**	**4,39**	94,69
15	1,52	0,78	12,70	12,62	**27,70**	**27,53**	**4,35**	93,33
20	2,32	0,78	12,73	12,68	**28,56**	**28,46**	**4,21**	90,48
24	2,05	0,78	12,80	12,65	**28,43**	**28,13**	**4,24**	90,17

Figures *italicized* are inputs and figures in bold are calculated values.

Average scheduled dwell time calculation

Trains	Number of train per cycle	Sch. dwell time [Sec.]
Regional trains	2	45
Commuter trains	6	45
Freight trains	1	105
	1	0
	Average	46,5
	Average[Min.]	**0,78**

Extended stops/dwell time

Number of block sections	Number of extended stops per cycle	Extended dwell time per cycle
5	1,41	86
10	1,26	54
15	2,17	64
20	5,30	222
24	2,02	91

Appendix B 2

Evaluation 4.1.2 Variation of block section adjacent to station

Entry delay perturbation

		Perturbation inputs			**Amount of lateness**		
Perturbation location	Total trains	%	Average delay [Min.]	Maximum delay [Min.]	# Perturbed trains	Total [Min.]	Per train [Min.]
Station A	1800	20%	1	5	355	381,87	0,21
Station C	1800	20%	1	5	335	333,43	0,19

Table of simulation output and capacity calculation

Block section adjacent to a station B	Lateness development departure [hh:mm:ss]	Scheduled dwell time [Sec.]	Actual travel time A to B [hh:mm:ss]	Actual travel time C to B [hh:mm:ss]	Total travel time A to C [Min.]	Total travel time C to A [Min.]	Capacity [Trains/hr]
1,50	00:00:05	**46,00**	00:20:28	00:20:24	**41,78**	**41,65**	**2,88**
1,60	00:00:05	**46,00**	00:20:28	00:20:24	**41,78**	**41,65**	**2,88**
1,70	00:00:04	**46,00**	00:20:29	00:20:24	**41,80**	**41,63**	**2,88**
1,80	00:00:04	**46,00**	00:20:29	00:20:24	**41,80**	**41,63**	**2,88**
1,90	00:00:05	**46,00**	00:20:29	00:20:24	**41,82**	**41,65**	**2,88**
2,00	00:00:04	**46,00**	00:20:29	00:20:24	**41,80**	**41,63**	**2,88**
2,10	00:00:05	**46,00**	00:20:29	00:20:25	**41,82**	**41,68**	**2,87**
2,20	00:00:05	**46,00**	00:20:29	00:20:24	**41,82**	**41,65**	**2,88**
2,30	00:00:04	**46,00**	00:20:27	00:20:25	**41,73**	**41,67**	**2,88**
2,40	00:00:05	**46,00**	00:20:28	00:20:24	**41,78**	**41,65**	**2,88**
2,50	00:00:05	**46,00**	00:20:29	00:20:24	**41,82**	**41,65**	**2,88**
2,60	00:00:04	**46,00**	00:20:29	00:20:24	**41,80**	**41,63**	**2,88**
2,70	00:00:04	**46,00**	00:20:29	00:20:24	**41,80**	**41,63**	**2,88**
2,80	00:00:05	**46,00**	00:20:29	00:20:24	**41,82**	**41,65**	**2,88**
2,90	00:00:04	**46,00**	00:20:29	00:20:24	**41,80**	**41,63**	**2,88**
3,00	00:00:04	**46,00**	00:20:29	00:20:24	**41,80**	**41,63**	**2,88**

Figures *italicized* are inputs and figures in bold are calculated values.

Appendix B 3

Evaluation 4.1.3: Inter station distance variation

Entry delay perturbation

		Perturbation inputs			Amount of lateness		
Perturbation location	Total trains	%	Average delay [Min.]	Maximum delay [Min.]	# Perturbed trains	Total [Min.]	Per train [Min.]
Station C	1800	20%	1	5	346	328,18	0,18
Station A	1800	20%	1	5	353	364,80	0,20

Table of simulation output and capacity calculation

Interstation distance [Km]	Lateness development departure [Min.]	Scheduled dwell time [Min.]	Actual travel time A to B [hh:mm:ss]	Actual travel time C to B [hh:mm:ss]	Total travel time A to B [Min.]	Total travel time C to B [Min.]	Capacity at Stn B Trains/hr	Max. Level of occup. per hour	Punctuality [%]	Number of extended stops per cycle	Extended dwell time per cycle [Min.]	Travelling time A to B [Min.]
15,0	19,80	**0,78**	00:13:26	00:12:54	**47,42**	**46,35**	**2,6**	79	79	15,00	21,9	13,4
17,5	4,40	**0,78**	00:14:34	00:14:41	**34,28**	**34,52**	**3,5**	45	94	4,00	5,1	14,6
20,0	0,23	**0,78**	00:16:37	00:16:32	**34,22**	**34,05**	**3,5**	18	100	3,33	1,9	16,6
22,5	0,07	**0,78**	00:18:32	00:18:27	**37,88**	**37,72**	**3,2**	15	100	3,18	1,6	18,5
25,0	0,07	**0,78**	00:20:28	00:20:23	**41,75**	**41,58**	**2,9**	14	100	3,32	1,6	20,5
27,5	0,07	**0,78**	00:22:24	00:22:19	**45,62**	**45,45**	**2,6**	13	100	3,06	1,6	22,4
30,0	0,07	**0,78**	00:24:19	00:24:15	**49,45**	**49,32**	**2,4**	12	100	5,04	1,6	24,3
32,5	0,07	**0,78**	00:26:16	00:26:11	**53,35**	**53,18**	**2,3**	11	100	3,33	1,6	26,3
35,0	0,07	**0,78**	00:28:12	00:28:07	**57,22**	**57,05**	**2,1**	10	100	2,58	1,6	28,2

37,5	0,07	**0,78**	00:30:08	00:30:03	**61,08**	**60,92**	**2,0**	10	100	2,46	1,6	30,1
40,0	0,08	**0,78**	00:32:02	00:31:58	**64,90**	**64,77**	**1,9**	9	100	3,04	1,5	32,0
42,5	0,07	**0,78**	00:33:59	00:33:54	**68,78**	**68,62**	**1,7**	9	100	2,72	1,6	34,0
45,0	0,07	**0,78**	00:35:53	00:35:50	**72,58**	**72,48**	**1,7**	8	100	3,03	1,4	35,9
47,5	0,07	**0,78**	00:37:51	00:37:46	**76,52**	**76,35**	**1,6**	8	100	2,81	1,6	37,9
50,0	0,08	**0,78**	00:39:45	00:39:42	**80,33**	**80,23**	**1,5**	8	100	2,26	1,4	39,8
52,5	0,07	**0,78**	00:41:43	00:41:38	**84,25**	**84,08**	**1,4**	7	100	3,15	1,6	41,7
55,0	0,10	**0,78**	00:43:38	00:43:41	**88,12**	**88,22**	**1,4**	7	100	*3,15*	*1,6*	43,6

Figures *italicized* are inputs and figures in bold are calculated values.

Appendix B 4

Evaluation 4.1.4: Station track size variation

Entry delay perturbation

		Perturbation inputs			Amount of lateness		
Perturbation location	Total trains	%	Average delay [Min.]	Maximum delay [Min.]	# Perturbed trains	Total [Min.]	Per train [Min.]
Station C	1800	20%	1	5	355	381,87	0,21
Station A	1800	20%	1	5	335	333,43	0,19

Table of simulation output and capacity calculation

Station B track size [m]	Lateness development departure [Sec.]	Scheduled dwell time [sec]	Actual travel time A to B [hh:mm:ss]	Actual travel time C to B [hh:mm:ss]	Total travel time A to C [hh:mm:ss]	Total travel time C to A [hh:mm:ss]	Capacity [Trains/hr]	Maximum level of occupation per hour	Punctuality
300	5	**47**	00:18:30	00:18:28	**37,87**	**37,80**	**3,17**	15,2	100,00
350	4	**47**	00:18:32	00:18:30	**37,92**	**37,85**	**3,17**	15,4	100,00
400	4	**47**	00:18:37	00:18:33	**38,08**	**37,95**	**3,16**	15,5	100,00
450	4	**47**	00:18:39	00:18:35	**38,15**	**38,02**	**3,15**	15,7	100,00
500	4	**47**	00:18:41	00:18:37	**38,22**	**38,08**	**3,15**	15,7	100,00
550	3	**47**	00:18:43	00:18:39	**38,27**	**38,13**	**3,14**	16,1	100,00
600	3	**47**	00:18:45	00:18:42	**38,33**	**38,23**	**3,13**	16,5	100,00
650	3	**47**	00:18:48	00:18:44	**38,43**	**38,30**	**3,13**	16,7	100,00
700	3	**47**	00:18:50	00:18:46	**38,50**	**38,37**	**3,12**	16,7	100,00
750	3	**47**	00:18:52	00:18:49	**38,57**	**38,47**	**3,12**	16,7	100,00
800	2	**47**	00:18:54	00:18:51	**38,62**	**38,52**	**3,11**	16,9	100,00
850	2	**47**	00:18:56	00:18:54	**38,68**	**38,62**	**3,10**	17,2	100,00
900	2	**47**	00:18:57	00:18:54	**38,72**	**38,62**	**3,10**	17,2	100,00
950	2	**47**	00:18:59	00:18:56	**38,78**	**38,68**	**3,10**	17,5	100,00
1000	4	**47**	00:18:57	00:19:00	**38,75**	**38,85**	**3,09**	17,5	100,00

Figures *italicized* are inputs and figures in bold are calculated values.

Appendix B 5

Evaluation 4.1.5: Allowance type variation

Entry delay perturbation

		Perturbation inputs			Amount of lateness		
Perturbation location	Total trains	%	Average delay [Min.]	Maximum delay [Min.]	# Perturbed trains	Total [Min.]	Per train [Min.]
Station A	1800	20%	1	5	347	345,62	0,19
Station C	1800	20%	1	5	360	360,85	0,20

Table of simulation output and capacity calculation

Allowance cases	Actual travel time A to B [Min.]	Actual travel time C to B [Min.]	Average scheduled dwell time [Min.]	Lateness development departure [Min.]	Total travel time A to C [Min.]	Total travel time C to A [Min.]	Capacity [Trains/hr]	Arrival delay per train [Sec.]	Departure delay per train [Sec.]	Punctuality
Run t.	13,90	13,63	**0,77**	3,52	**32,09**	**31,55**	**3,77**	30	52	91,58
Base line	13,32	13,23	**0,77**	4,10	**31,50**	**31,34**	**3,82**	9	34	95,29
Buffer t.	13,35	13,25	**0,77**	4,17	**31,64**	**31,44**	**3,81**	10	35	94,80
Dwell t.	13,23	13,18	**0,77**	0,55	**27,79**	**27,69**	**4,33**	9	13	96,92
All	14,00	13,57	**0,77**	0,78	**29,55**	**28,69**	**4,12**	9	14	95,41

Words *italicized* are alternatives and figures in bold are calculated values.

Appendix B 6

Evaluation 4.2.1: Block section variation with station dwell time.

Entry delay perturbation

		Perturbation inputs			**Amount of lateness**		
Perturbation location	Total trains	%	Average delay [Min.]	Maximum delay [Min.]	# Perturbed trains	Total [Min.]	Per train [Min.]
Station A	1440	10%	1	5	140	120,37	0,08
Station C	1440	10%	1	5	128	161,07	0,11

Average head way time calculation between trains in the group.

In the first general scenario the time tables were scheduled in such a manner that a single trains departing from both A and C occupies the section until they meet at station B. Unlike the first general scenario, here three trains are scheduled to depart from station A and C, one after the other with minimum headway and the track section between the stations are occupied with three trains consecutively. In order to calculate the capacity the average headway should be estimated from scheduled time table. These are presented with the following table and the respective values are entered in the third column the next table (Table of simulation output and capacity calculation)

Average time between trains at departing stations A and C

Dwell time options at station B	Average time between trains (head way between trains in group) [Minutes]					
	Block section variation between stations					
	1 km	**1,5 km**	**2 km**	**2,5 km**	**3,0 km**	**3,5 km**
1	3,10	3,08	3,25	3,38	3,65	3,90
2	3,10	3,08	3,25	3,38	3,65	3,93
3	3,10	3,08	3,25	3,37	3,65	3,95
4	3,10	3,08	3,25	3,37	3,65	3,95
5	3,10	3,08	3,25	3,37	3,65	3,95

Table of simulation output and capacity calculation

Block section [Km]	Time between trains in a group [Min.]	Actual travel time A to B [Min.]	Actual travel time C to B [Min.]	Average Scheduled dwell time [Min.]	Punctuality [%]	Number of late trains at Arrival	Number of late trains at depart.	Lateness development departure [Min.]	Total travel time A to C [Min.]	Total travel time C to A [Min.]	Capacity [Trains/hr]	Extended stops per cycle	Extended dwell time per cycle [Min.]
	3,10	11,50	11,78	**4,28**	95,98	7,43	9,23	0,15	**30,53**	**31,09**	**11,69**	4,49	3,95
	3,10	11,48	11,80	**4,61**	96,45	7,42	8,85	0,12	**30,79**	**31,43**	**11,57**	3,74	3,12
1,0	**3,10**	11,42	11,73	**4,94**	97,79	7,20	8,34	0,08	**30,96**	**31,59**	**11,51**	2,62	2,05
	3,10	11,42	11,70	**5,28**	98,06	6,87	7,84	0,08	**31,29**	**31,86**	**11,40**	2,43	2,02
	3,10	11,45	11,70	**5,61**	98,07	6,73	7,54	0,08	**31,69**	**32,19**	**11,27**	2,38	2,13
	3,08	12,13	12,17	**4,43**	95,55	13,95	15,94	0,23	**32,01**	**32,08**	**11,23**	7,79	6,42
	3,08	12,07	12,10	**4,82**	97,25	13,94	15,19	0,17	**32,21**	**32,27**	**11,17**	4,69	4,62
1,5	**3,08**	12,03	12,07	**5,09**	97,90	13,84	14,82	0,13	**32,38**	**32,44**	**11,11**	3,77	3,62
	3,08	12,00	12,05	**5,43**	98,30	13,82	14,58	0,10	**32,61**	**32,71**	**11,02**	2,80	2,87
	3,08	11,98	12,03	**5,76**	98,56	13,71	14,40	0,10	**32,91**	**33,01**	**10,92**	2,33	2,43
2,0	**3,25**	11,63	11,87	**4,59**	96,27	11,30	13,12	0,18	**31,29**	**31,76**	**11,42**	8,36	4,80

	3,25	11,65	11,78	**4,94**	97,37	11,40	12,83	0,15	**31,64**	**31,91**	**11,33**	4,85	4,08
	3,25	11,60	11,77	**5,28**	97,35	11,23	12,37	0,10	**31,83**	**32,16**	**11,25**	3,90	2,88
	3,25	11,60	11,70	**5,61**	97,11	11,21	12,24	0,08	**32,14**	**32,34**	**11,17**	3,28	2,38
	3,25	11,55	11,70	**5,94**	97,84	10,95	11,88	0,07	**32,36**	**32,66**	**11,07**	2,73	2,08
	3,38	11,83	12,05	**4,78**	94,53	11,27	13,47	0,32	**32,14**	**32,58**	**11,13**	10,06	9,03
	3,38	11,77	11,95	**5,11**	96,05	10,75	12,73	0,22	**32,24**	**32,61**	**11,10**	7,39	6,35
2,5	**3,37**	11,68	11,82	**5,44**	98,06	11,07	12,23	0,13	**32,31**	**32,58**	**11,10**	4,86	4,07
	3,37	11,67	11,77	**5,79**	98,44	10,74	11,77	0,12	**32,61**	**32,81**	**11,01**	4,44	3,82
	3,37	11,65	11,70	**6,12**	98,87	10,58	11,40	0,10	**32,89**	**32,99**	**10,93**	3,70	2,92
	3,65	12,72	13,13	**5,18**	92,40	17,14	20,52	0,52	**34,78**	**35,61**	**10,23**	16,12	16,38
	3,65	12,35	12,60	**5,51**	95,93	15,90	18,09	0,20	**34,06**	**34,56**	**10,49**	9,03	6,87
3,0	**3,65**	12,30	12,48	**5,84**	96,61	15,64	16,71	0,15	**34,24**	**34,61**	**10,46**	5,95	5,40
	3,65	12,25	12,42	**6,18**	97,21	15,39	16,35	0,13	**34,46**	**34,79**	**10,40**	5,16	4,77
	3,65	12,23	12,37	**6,51**	97,54	15,20	15,85	0,10	**34,73**	**34,99**	**10,33**	4,25	3,78
	3,90	12,87	13,43	**5,58**	92,06	18,72	21,95	0,55	**35,76**	**36,90**	**9,91**	17,11	18,53
	3,93	12,47	12,75	**6,19**	95,92	18,82	21,02	0,18	**35,24**	**35,81**	**10,13**	8,33	6,75
3,5	**3,95**	12,40	12,62	**6,51**	96,96	18,80	19,58	0,10	**35,36**	**35,80**	**10,12**	7,12	5,50
	3,95	12,38	12,53	**6,85**	97,27	18,38	19,46	0,10	**35,66**	**35,96**	**10,05**	5,66	3,78
	3,95	12,37	12,52	**7,18**	97,43	18,37	19,35	0,08	**35,95**	**36,25**	**9,97**	4,90	3,22

Figures *italicized* are inputs and figures in bold are calculated values.

Appendix B 7

Evaluation 4.2.2: Block section variation with speed of trains.

Cumulative speed calculation for speed alternatives

Traffic	Speed variation [Km/hr]				
	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Composition of trains
Regional	100	120	140	160	16,70%
Commuter	80	100	120	140	66,70%
Freight	60	70	80	90	16,70%
Cumulative speed	**80**	**98**	**117**	**135**	

Cumulative speed is the sum of weighted speed by respective composition,

$$Example, cumulative\ speed\ for\ alternative\ 1, \quad V_{ave} = \frac{100x16.7\,\% + 80x66,7\% + 60x16,7\%}{100\%} = 80\ ^{Km}/_{hr}$$

Entry delay perturbation

Perturbation inputs					Amount of lateness					
					Station A			Station C		
Average Speed of trains	Total trains at each station	%	Average delay [Min.]	Maximum delay [Min.]	# Perturbed trains	Total [Min.]	Per train [Min.]	# Perturbed trains	Total [Min.]	Per train [Min.]
80	1440	10%	1	5	135	119,15	0,083	121	117,40	0,082
98	1440	10%	1	5	133	150,30	0,104	151	153,27	0,106
117	1440	10%	1	5	135	126,70	0,088	149	162,95	0,113
135	1440	10%	1	5	138	143,62	0,100	153	154,25	0,107

Average time between trains at departing stations A and C

Average time between trains departure at station A and C (head way between trains in a group) [Minutes]						
Speed variations [km/hr]	Block section variation between stations					
	1 km	**1,5 km**	**2 km**	**2,5 km**	**3,0 km**	**3,5 km**
80	3,02	3,43	3,70	4,08	4,57	4,98
98	3,07	3,32	3,70	3,88	4,20	4,43
117	3,02	3,25	3,43	3,67	3,98	4,18
135	3,12	3,18	3,20	3,38	3,65	3,90

Table of simulation output and capacity calculation

Speed [Km/hr]	**Block sections alternative [Km]**	**Time interval b/n trains [Min.]**	**Actual travel time A to B [Min.]**	**Actual travel time C to B [Min.]**	**Scheduled dwell time [Min.]**	**Lateness arrival [Min.]**	**Lateness departure [Min.]**	**Punctuality [%]**	**Number of late trains at Arrival**	**Number of late trains at departure**	**Lateness development departure [Min.]**	**Total travel time A to C [Min.]**	**Total travel time C to A[Min.]**	**Capacity [Trains/hr]**
80	*1,0*	3,02	17,67	17,77	4,47	0,55	0,73	99,26	15,6	19,62	0,18	**43,00**	**43,20**	**8,4**
	1,5	3,43	18,50	18,63	5,01	0,63	0,77	99,13	19,6	21,85	0,13	**45,58**	**45,84**	**7,9**
	2,0	3,70	17,95	17,98	5,43	0,90	1,05	98,72	20,2	22,38	0,17	**45,19**	**45,26**	**8,0**
	2,5	4,08	18,00	18,10	6,09	0,98	1,17	98,81	21,9	23,91	0,18	**46,35**	**46,55**	**7,7**
	3,0	4,57	18,82	18,85	6,84	0,97	1,10	99,97	21,4	23,21	0,13	**49,18**	**49,24**	**7,3**
	3,5	4,98	18,62	18,73	7,68	0,73	0,87	100,00	22,2	24,00	0,13	**50,03**	**50,26**	**7,2**
98	*1,0*	3,07	14,95	15,00	4,27	1,78	2,03	95,56	12,5	14,85	0,25	**37,49**	**37,59**	**9,6**
	1,5	3,32	15,58	15,58	4,54	1,35	1,53	97,36	14,6	16,76	0,18	**39,21**	**39,21**	**9,2**

	2,0	3,70	15,03	15,10	5,07	1,83	2,10	94,86	15,3	18,04	0,27	**39,10**	**39,23**	**9,2**
	2,5	3,88	15,15	15,25	5,53	1,93	2,22	94,80	18,5	21,38	0,27	**39,98**	**40,18**	**9,0**
	3,0	4,20	16,02	16,18	5,98	1,57	1,83	96,75	21,6	23,74	0,27	**42,48**	**42,81**	**8,4**
	3,5	4,43	16,48	16,67	6,47	2,32	2,70	94,19	21,2	23,28	0,38	**44,25**	**44,62**	**8,1**
117	*1,0*	3,02	13,08	13,27	3,91	2,48	2,82	93,64	11,7	14,03	0,33	**33,43**	**33,79**	**10,7**
	1,5	3,25	13,77	13,65	4,34	2,75	3,05	92,53	12,6	14,93	0,28	**35,40**	**35,17**	**10,2**
	2,0	3,43	13,12	13,22	4,71	2,05	2,33	94,39	11,1	12,97	0,28	**34,66**	**34,86**	**10,4**
	2,5	3,67	13,23	13,52	5,06	2,10	2,45	93,94	17,1	18,87	0,35	**35,54**	**36,11**	**10,0**
	3,0	3,98	13,97	14,25	5,52	2,63	3,07	92,15	18,0	21,22	0,43	**37,87**	**38,43**	**9,4**
	3,5	4,18	14,75	14,73	6,00	2,72	3,02	90,24	19,9	23,22	0,30	**39,98**	**39,95**	**9,0**
135	*1,0*	3,12	11,62	11,85	4,29	2,30	2,58	93,37	8,6	10,30	0,28	**30,92**	**31,39**	**11,6**
	1,5	3,18	12,18	12,27	4,48	2,63	2,88	93,32	13,9	15,42	0,25	**32,28**	**32,44**	**11,1**
	2,0	3,20	11,73	11,92	4,51	2,18	2,38	94,20	13,7	15,38	0,20	**31,37**	**31,74**	**11,4**
	2,5	3,38	11,90	12,05	4,78	2,37	2,73	92,84	10,9	13,09	0,37	**32,33**	**32,63**	**11,1**
	3,0	3,65	12,75	13,22	5,18	2,65	3,27	91,35	16,9	20,26	0,62	**34,94**	**35,88**	**10,2**
	3,5	3,90	12,85	13,57	5,58	2,98	3,65	91,18	18,6	21,98	0,67	**35,85**	**37,28**	**9,8**

Figures *italicized* are inputs and figures in bold are calculated values.

Appendix B 8

<u>Evaluation 4.2.3 Setting time variation with block section</u>

Entry delay perturbation

		Perturbation inputs			Amount of lateness		
Perturbation location	Total trains	%	Average delay [Min.]	Maximum delay [Min.]	# Perturbed trains	Total [Min.]	Per train [Min.]
Station A	1440	10%	1	5	135	121,13	0,08
Station C	1440	10%	1	5	143	123,72	0,09

Table of simulation output and capacity calculation

Block section [Km.]	Interlocking setting time [Min.]	Headway between trains in a group [Min.]	Actual travel time A to B [Min.]	Actual travel time C to B [Min.]	Scheduled dwell time [Min.]	Lateness arrival [Min.]	Lateness departure [Min.]	Punctuality [%]	Lateness development departure [Min.]	Total travel time A to C [Min.]	Total travel time C to A [Min.]	Capacity of station B [Trains/hr]	Number of extended stops per cycle	Extended dwell time per cycle [Min.]
1.5	*10*	*3,23*	12,33	12,27	**4,78**	1,75	2,07	95,93	0,32	**32,99**	**32,86**	**10,93**	10,55	7,93
	15	*3,35*	12,38	12,40	**5,00**	1,92	2,25	95,43	0,33	**33,45**	**33,48**	**10,76**	10,46	8,57
	20	*3,47*	12,33	12,32	**5,25**	2,02	2,33	95,08	0,32	**33,70**	**33,67**	**10,69**	10,79	8,03
	25	*3,58*	12,40	12,28	**5,54**	1,87	2,20	95,60	0,33	**34,26**	**34,03**	**10,54**	10,60	8,33
2.5	*10*	*3,45*	12,10	12,15	**5,18**	2,48	2,87	92,95	0,38	**33,21**	**33,31**	**10,82**	11,58	11,40
	15	*3,57*	12,17	12,47	**5,31**	2,90	3,33	91,37	0,43	**33,65**	**34,25**	**10,61**	19,96	15,73
	20	*3,63*	12,05	12,48	**5,56**	3,35	3,82	89,65	0,47	**33,76**	**34,63**	**10,53**	14,00	13,12
	25	*3,73*	12,02	12,25	**5,88**	2,72	3,05	92,88	0,33	**33,98**	**34,45**	**10,52**	12,12	10,10
3.5	*10*	*3,98*	13,02	13,25	**5,92**	3,12	3,57	90,16	0,45	**36,39**	**36,85**	**9,83**	17,18	14,27
	15	*4,18*	13,22	13,40	**6,26**	3,28	3,78	91,19	0,50	**37,38**	**37,75**	**9,58**	18,36	16,80
	20	*4,15*	13,30	13,57	**6,42**	3,38	3,87	89,84	0,48	**37,65**	**38,19**	**9,49**	15,55	14,93
	25	*4,25*	13,42	13,47	**6,71**	3,13	3,45	90,07	0,32	**38,11**	**38,21**	**9,43**	13,65	11,07

Figures *italicized* are inputs and figures in bold are calculated values.

Appendix B 9

4.2.4 Release time variation with trains Speed

Entry delay perturbation

		Perturbation inputs			Amount of lateness		
Perturbation location	Total trains	%	Average delay [Min.]	Maximum delay [Min.]	# Perturbed trains	Total [Min.]	Per train [Min.]
Station A	1440	10%	1	5	152	149,12	0,10
Station C	1440	10%	1	5	138	137,23	0,10

Table of simulation output and capacity calculation

Speed [km/hr]	Interlocking Release time [Sec.]	Headway between trains in a group [Min.]	Actual travel time A to B [Min.]	Actual travel time C to B [Min.]	Scheduled dwell time [Min.]	Average lateness arrival [Min.]	Average lateness departure [Min.]	Punctuality [%]	Lateness development departure [Min.]	Total travel time A to C [Min.]	Total travel time C to A [Min.]	Capacity of Station B [trains/hr]	Number of extended stops per cycle	Extended dwell time per cycle	Average travelling time
62	*10*	**4,43**	22,43	22,48	**7,69**	0,68	0,78	99,83	0,12	**57,10**	**57,20**	**6,30**	8,18	4,05	22,46
	15	**4,40**	22,42	22,53	**7,77**	0,70	0,82	99,93	0,12	**57,12**	**57,35**	**6,29**	10,20	5,13	22,48
	20	**4,48**	22,45	22,55	**8,00**	0,73	0,85	99,93	0,12	**57,50**	**57,70**	**6,25**	9,91	4,85	22,50
	25	**4,53**	22,47	22,60	**8,24**	0,77	0,88	99,93	0,12	**57,83**	**58,09**	**6,21**	8,56	4,33	22,53
98	*10*	**3,83**	15,20	15,37	**5,47**	1,88	2,20	95,15	0,32	**40,02**	**40,35**	**8,96**	13,47	10,40	15,28
	15	**3,93**	15,28	15,47	**5,73**	1,87	2,17	95,48	0,30	**40,53**	**40,90**	**8,84**	13,45	9,97	15,38
	20	**3,97**	15,57	15,82	**5,93**	2,55	2,97	92,60	0,42	**41,45**	**41,95**	**8,63**	16,39	13,68	15,69
	25	**4,02**	15,75	15,92	**6,13**	2,57	2,92	93,17	0,35	**41,99**	**42,33**	**8,54**	18,08	12,45	15,83
135	*10*	**3,40**	11,93	12,20	**4,89**	2,17	2,57	93,80	0,40	**32,56**	**33,09**	**10,97**	12,63	12,08	12,07
	15	**3,47**	11,97	12,28	**5,07**	2,32	2,77	93,55	0,45	**32,92**	**33,55**	**10,83**	13,27	13,13	12,13
	20	**3,65**	12,08	12,42	**5,42**	2,90	3,32	93,98	0,42	**33,65**	**34,32**	**10,59**	17,67	13,17	12,25
	25	**3,68**	11,83	12,03	**5,65**	2,62	3,00	93,20	0,38	**33,39**	**33,79**	**10,72**	12,27	11,30	11,93

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4.2.4 Perturbation variation with trains Speed

Speed			Perturbation inputs			Amount of lateness		
	Perturbation location	Total trains	%	Average delay [Min.]	Maximum delay [Min.]	# Perturbed trains	Total [Min.]	Per train [Min.]
50% Vmax	A	1440	10%	1	5	124	128,3	0,09
	C	1440	10%	1	5	147	146,1	0,10
	A	1440	15%	1	5	229	238,4	0,17
	C	1440	15%	1	5	222	226,4	0,16
	A	1440	20%	1	5	287	281,5	0,20
	C	1440	20%	1	5	286	287,9	0,20
	A	1440	25%	1	5	347	342,0	0,24
	C	1440	25%	1	5	356	361,8	0,25
	A	1440	30%	1	5	427	439,8	0,31
	C	1440	30%	1	5	412	419,0	0,29
	A	1440	35%	1	5	509	525,3	0,36
	C	1440	35%	1	5	524	502,3	0,35
75% Vmax	C	1440	10%	1	5	128	158,7	0,11
	A	1440	10%	1	5	140	120,4	0,08
	C	1440	15%	1	5	218	211,2	0,15
	A	1440	15%	1	5	207	209,0	0,15
	C	1440	20%	1	5	307	326,7	0,23
	A	1440	20%	1	5	282	296,9	0,21
	C	1440	25%	1	5	354	333,2	0,23

	A	1440	25%	1	5	364	362,9	0,25
	C	1440	30%	1	5	423	449,5	0,31
	A	1440	30%	1	5	412	405,7	0,28
	C	1440	35%	1	5	519	497,0	0,35
	A	1440	35%	1	5	482	495,1	0,34
100 % Vmax	C	1440	10%	1	5	128	116,0	0,08
	A	1440	10%	1	5	140	147,1	0,10
	C	1440	15%	1	5	212	226,9	0,16
	A	1440	15%	1	5	228	222,2	0,15
	C	1440	20%	1	5	289	298,5	0,21
	A	1440	20%	1	5	280	283,7	0,20
	C	1440	25%	1	5	382	392,3	0,27
	A	1440	25%	1	5	357	387,2	0,27
	C	1440	30%	1	5	428	430,4	0,30
	A	1440	30%	1	5	430	439,3	0,31
	C	1440	35%	1	5	483	528,6	0,37
	A	1440	35%	1	5	492	482,7	0,34

Table of simulation output and capacity calculation

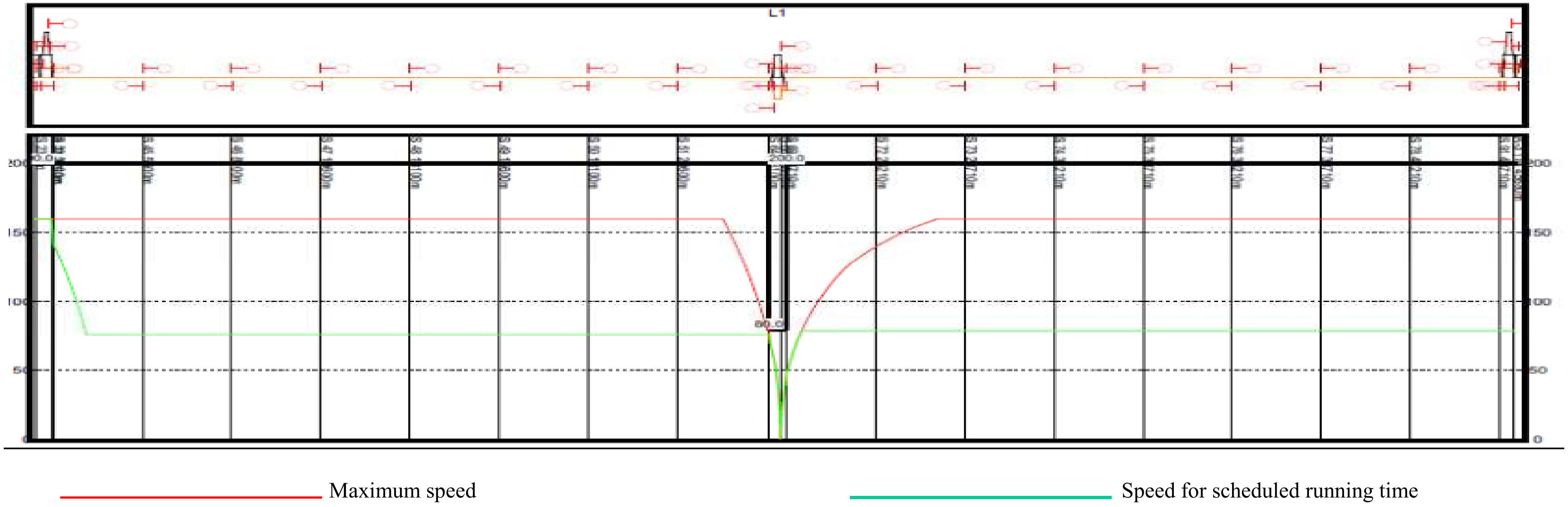
Max Speed of trains in [%]	Perturbation [%]	Time interval between trains in a group [Min]	Actual travel time A to B [Min]	Actual travel time C to B [Min]	Scheduled dwell time [Min]	Lateness development departure minutes [Min]	Total travel time A to C [Min]	Total travel time C to A [Min]	Capacity [Trains/hr]	Punctuality
50 % Vmax	*10*	5,53	21,02	21,08	6,43	0,13	**54,13**	**54,26**	**6,64**	99,9
	15	5,53	21,15	21,18	6,43	0,13	**54,39**	**54,46**	**6,61**	99,7
	20	5,53	21,13	21,17	6,43	0,15	**54,38**	**54,44**	**6,62**	99,9
	25	5,53	21,20	21,22	6,43	0,17	**54,53**	**54,56**	**6,60**	99,5
	30	5,53	21,22	21,27	6,43	0,17	**54,56**	**54,66**	**6,59**	99,6
	35	5,53	21,23	21,25	6,43	0,18	**54,61**	**54,64**	**6,59**	99,6
75 % Vmax	*10*	5,53	15,07	15,43	4,99	0,35	**41,01**	**41,74**	**8,70**	94,4
	15	5,53	15,30	15,67	4,99	0,55	**41,67**	**42,41**	**8,56**	90,9
	20	5,53	15,52	15,60	4,99	0,47	**42,02**	**42,19**	**8,55**	87,9
	25	5,53	15,65	15,92	4,99	0,68	**42,51**	**43,04**	**8,42**	86,7
	30	5,53	15,58	15,73	4,99	0,52	**42,21**	**42,51**	**8,50**	87,5
	35	5,53	15,77	15,85	4,99	0,73	**42,79**	**42,96**	**8,40**	83,6
100% Vmax	*10*	5,53	11,82	11,92	4,89	0,27	**34,32**	**34,52**	**10,46**	94,8
	15	5,53	12,00	12,17	4,89	0,42	**34,84**	**35,17**	**10,28**	92,1
	20	5,53	12,22	12,33	4,89	0,53	**35,39**	**35,62**	**10,14**	89,3
	25	5,53	12,32	12,57	4,89	0,62	**35,67**	**36,17**	**10,02**	85,4
	30	5,53	12,28	12,45	4,89	0,55	**35,54**	**35,87**	**10,08**	86,0
	35	5,53	12,47	12,67	4,89	0,75	**36,11**	**36,51**	**9,92**	85,2

Figures *italicized* are inputs and figures in bold are calculated values

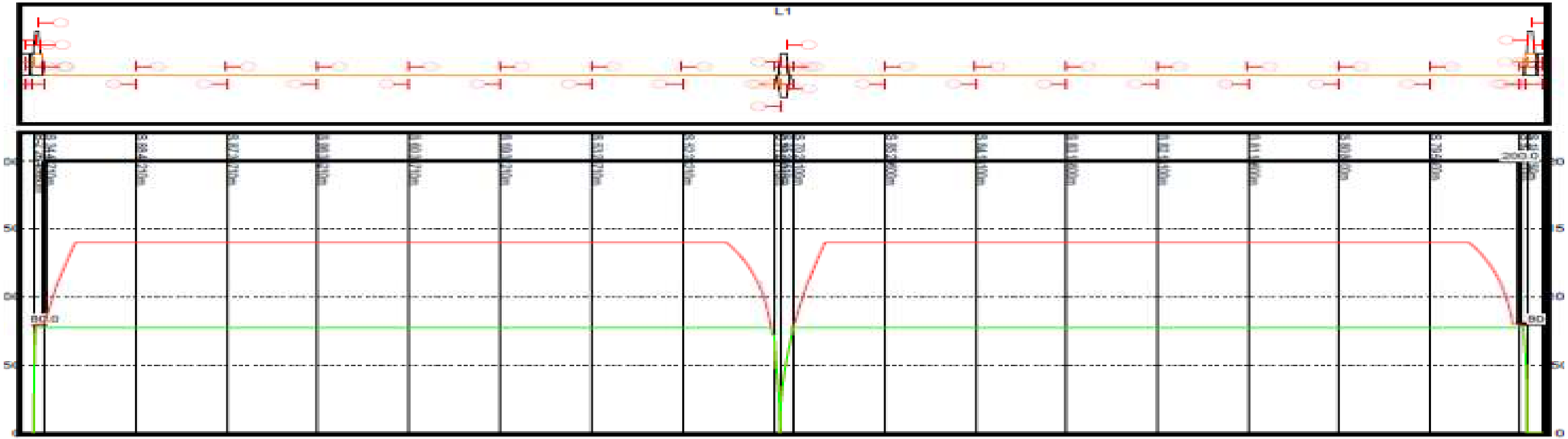
Appendix C. Speed- distance graphs of trains

Evaluation 4.1.3 Variation of inter station distance

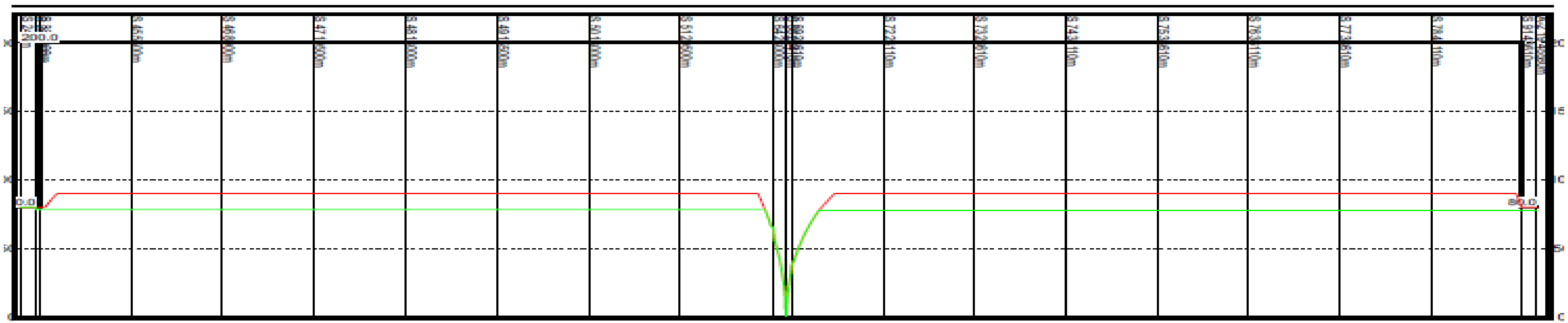
Regional train



Commuter train



Freight train



Maximum speed

Speed for scheduled running time

Appendix D. Estimation of cost of construction

	Single track	Double track
Earth work	30,6	*30,6 x 1,2 = 36,72*
Track(ballast,sub-ballast)	7,6	*7,6 x 1,6 = 12,16*
Total cost MSEK/km	38,2	*48,88*

1.Tables of calculations for station tracks and single tracks between stations: First scenario

Station	No of tracks	Length of track [Km]	Cost [MSEK/Km]	Multiplying factor	Total Cost [MSEK]
A	3	1,75	48,88	1,5	128,31
B	3	0,4	48,88	1,5	29,33
C	3	1,75	48,88	1,5	128,31
				Sum	285,9

Multiplying factors are taken 1,5 with assumption that 3 tracks in station make half of 3 double tracks, i.e., ½ * 3 = 1,5

Single track	Length [Km]	Cost [MSEK/Km]	Total Cost [MSEK]
Station A - Station B	20	38,2	764
Station B - Station C	20	38,2	764
		Sum	1528

Total cost of construction for station and track	1813,9 MSEK

<u>2.Tables of calculations for station tracks and single tracks between stations: Second scenario</u>

Station	No of tracks	Length of track [Km]	Cost [MSEK/Km]	Multiplying factor	Total Cost [MSEK]
A	3	1,75	48,88	1,5	128,31
B	6	0,72	48,88	3	105,58
C	3	1,75	48,88	1,5	128,31
				Sum	362,2

Multiplying factor is taken 3 for station B with assumption that 6 tracks in station make 3 double tracks.

Single track	Length [Km]	Cost [MSEK/Km]	Total Cost [MSEK]
Station A - Station B	20	38,2	764
Station B - Station C	20	38,2	764
		Sum	1528

Cost of station and track construction	1890,2 MSEK

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