Visual and Analytical support for Real-time evaluation of Railway traffic re-scheduling Alternatives during disturbances

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Disturbances in the railway network are frequent and to some extent, inevitable. When this happens, the traffic dispatchers need to re-schedule the train traffic and there is a need for decision support in this process. One purpose of such a decision support system would be to visualize the relevant, alternative re-scheduling solutions and benchmark them based on a set of relevant train traffic attributes which quantify the effects of each solution. Currently, there are two research projects financed by the Swedish Transport Administration (i.e. Trafikverket) which focus on developing decision support to assist the Swedish train traffic managers: The STEG project and the EOT project. Within the STEG project, researchers at Uppsala University in cooperation with Trafikverket are developing a graphical user interface (referred to as the STEG graph). Within the EOT project, researchers at Blekinge Institute of Technology (BTH) are developing fast re-scheduling algorithms to propose to the Swedish train traffic dispatchers a set of relevant re-scheduling alternatives when disturbances occur. However, neither the STEG graph nor the EOT algorithms are at this point designed to evaluate, benchmark and visualize the alternative re-scheduling solutions.

The main objective of this work is therefore to identify and analyze different train traffic attributes and how to use the selected relevant ones for benchmarking re-scheduling solutions. This involves enhancing an existing visual tool (EOT GUI) and using this extended version (referred to as the EOT GUI+) to demonstrate and evaluate the benchmarking of different re-scheduling solutions based on the selected train traffic attributes.

The train traffic attributes found in the literature (foremost research publications and documents by Trafikverket) were collected and analyzed. A subset of the most commonly used attributes found were then selected and their applicability in benchmarking re-scheduling solutions for the Swedish train traffic system was further analyzed. The formulas for calculating each of the attribute values were either found in the literature and possibly modified, or defined within this thesis project. In order to assess the use of the attributes for benchmark solutions, experiments were conducted using the enhanced visual tool EOT GUI+ and a set of sample solutions for three different disturbance scenarios provided by the EOT project. The tool only performs a benchmark of two solutions at a time (i.e. a pair wise benchmark) and computes the attribute values for the chosen attributes. The literature review and attribute analysis resulted in a first set of ten different attributes to use including e.g. total final delay (with a delay threshold value of 1 and 5 minutes respectively), maximum delay, total accumulated delay, total delay cost, number of delayed trains and robustness. The formulas to compute these attribute values were implemented and applied to the sample solutions in the experiments. The first phase of the experiments showed that in one of the disturbance scenarios, some of the attribute values were in conflict and that none of re-scheduling solution was dominating the others. This observation led to that the set of attributes needed to be narrowed down and internally prioritized. Based on the experimental results and the analysis of what the research community and the main stakeholder (i.e. Trafikverket) consider are the most important attributes in this context, the final set of attributes to use includes average final delay, maximum delay of a single train, total number of delayed trains and robustness.

The contribution of this thesis is primarily the review and analysis of what attributes to use when performing a benchmark of re-scheduling solutions in real-time train traffic disturbance management. Furthermore, this thesis also contributes by performing an experimental assessment of how the attributes and their formulas could work in a pair-wise, quantitative benchmark for a set of disturbance scenarios and which issues that may occur due to conflicting objectives and attribute values.

Concerning the enhancement of the visual tool and the visualization of the re-scheduling solutions, the experimental evaluation and analysis shows that the tool would not fit directly to the needs of the train dispatchers. This work should therefore only be seen as a starting point for the researchers whom are working with the development of decision support systems in this context. Furthermore, several iterative experiments have been conducted to select the appropriate attributes for benchmarking solutions and suggesting the best re-scheduling solution. During the experiments, we have used a limited set of different problem instances (2+2+7) representing three different types of disturbances. The performance of the enhanced visual tool EOT GUI+ and its functionalities should ideally also be analyzed further and improved by experimenting with a larger number of instances, for other parts of the Swedish railway network and in co-operation with the real users, i.e. the dispatchers.

**Keywords:** Train traffic, Disturbance management, Train delay, Train traffic dispatching.
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1 INTRODUCTION

1.1 Background and Motivation

Disturbances in the railway network are frequent and to some extent, inevitable [6, 40]. In Sweden, the arrival punctuality of the railway traffic in was 88% in 2010, which is the worst year during the time period 2004-2010 [40]. A disturbance refers here to some kind of malfunctioning of the network, rolling-stock or any other incident preventing the train traffic from running according to the timetable and often resulting in train delays and unpunctual arrivals. The initial disturbance can sometimes be small, but due to the congested network the knock-on effects (i.e. one delayed train may delay another train, which in turn may delay a third train, etc) can be severe. In [37] it is mentioned that in 2006, 31% of the reported delays in the Swedish railway network were knock-on delays.

When disturbances occur, the train dispatchers (i.e. the train traffic managers) need to re-schedule the train traffic and there is a need for decision support in this process. The decision support system should assist the dispatchers by suggesting and clearly visualizing the alternative re-scheduling solutions and their consequences. Trafikverket (formerly named Banverket, the Swedish Transport Administration) is funding two research projects in this area: The EOT project [37] and the STEG project [20].

Figure 1. Research gap in Swedish real-time train traffic.

Figure 1 depicts the motivation of doing this research; the triangle shows the research area of our thesis. The problem is there is no decision support to benchmark and visualize the alternative re-scheduling solutions for Swedish train traffic dispatchers. Within the EOT project, researchers at BTH are developing algorithms to quickly provide solutions. These algorithms serve to assist the Swedish train traffic dispatchers with a set of relevant re-scheduling alternatives when disturbances occur. A smaller set of relevant attributes and objectives are considered when benchmarking the alternatives.

Within the STEG project, researchers at Uppsala University in co-operation with Trafikverket are developing a graphical user interface (referred to as the STEG graph) to facilitate train traffic control [42], which becomes increasingly important during disturbances. However, neither the STEG graph nor the EOT algorithms are at this point designed to evaluate benchmark and visualize the alternative re-scheduling solutions.

Depending on the disturbance situation, the train traffic needs to be re-scheduled in different ways. Hence various factors and aspects are to be considered while analyzing and comparing solutions for a train traffic disturbance problem. Examples on important train traffic attributes are number of delayed...
trains, total delay (in time units), total delay cost and robustness. A good decision support system is needed to benchmark the re-scheduling solutions based on such train traffic attributes, so the research falls under Decision support systems in the field of Computer Science.

Initially, the train traffic attributes that are important to use in such a benchmark and how to compute them need to be identified. Second, how to present the train traffic attribute values which quantify the solutions’ suitability need to be analyzed. In order to demonstrate how such a benchmark and evaluation of re-scheduling alternatives could be done, a visual tool would be beneficial. EOT has already developed a visual tool, but it has a functionality to analyze one re-scheduling solution at a time. Hereafter in our thesis the existing visual tool is referred to as the “EOT GUI.” This “EOT GUI” has to be enhanced with various functionalities for analyzing two different re-scheduling solutions, to evaluate them, and to suggest the best ones of the analyzed solutions for a real-time situation. In our thesis, the Enhanced “EOT GUI” is referred to as “EOT GUI+.”

The “EOT GUI+” serves to display a pair-wise comparison of re-scheduling solutions. The comparison of two different solutions can be made with the help of the identified set of train traffic attributes and their values. The relevant train traffic attributes will be investigated via a literature review and also based on given realistic scenarios provided by the EOT project.

To exemplify, consider a scenario where the comparison of two solutions with respect to the attributes: total number of delayed trains and total final delay. Total number of delayed trains [38] refers here to the number of trains that arrive at their final destination with a delay larger than zero and Total final train delay [38] refers to the sum of the positive delays of the trains at their final destinations.

Let A be the re-scheduling solution where two trains are planned to be delayed at their final destination (4 minutes and 10 minutes delayed respectively) while B is the solution where instead only one train will be delayed (by 24 minutes). If we consider solution B, then the total number of delayed trains is less than in A. However, the total train delay in B is larger than in A. That is, in B the total train delay is 24 minutes whereas in A the total train delay is 14 minutes. If we evaluate and compare these two alternative solutions based on the attribute total final delay, we can conclude that solution A is to be selected. Additional attributes may, however, be necessary to use when comparing alternative solutions in order to pick the most suitable one. Hence one main part of this thesis work is to find those relevant attributes which can be used to suggest suitable re-scheduling solutions to the train traffic dispatchers.

1.2 Aims and Objectives

The aims and objectives of our thesis are as follows.

- Identify and analyze the different train traffic attributes and how to use them for benchmarking solutions.
- Enhance the “EOT GUI” for benchmarking and visualizing the solutions.
- Demonstrate the benchmarking of different solutions based on the train traffic attributes using the enhanced “EOT GUI”, i.e. “EOT GUI+”.

1.3 Research Methodology

1.3.1 Research Questions

RQ1: What are the relevant and important train traffic attributes to consider when benchmarking different solutions in real-time train traffic management?
RQ2: How can these attribute values be computed and used?
RQ3: How to visualize the pair-wise comparison of re-scheduling solutions?
RQ4: How to analyze and benchmark the solutions based on the train traffic attributes found?

1.3.2 Research Process

To carry out the research process research methodologies are needed. Research methodology is the action plan that links methods to outcomes [10]. The methods are chosen based on our research. The methods are the techniques and procedures which are implied to produce outcome. The research methodologies applied to our thesis are taken from the book J. Creswell [10], which acts as base structure for our thesis. There are two main approaches to use in research; qualitative and quantitative approaches [10]. Qualitative approach is the process of research, which involves collection of data, analysis and interpretation that researcher propose for their studies. The methods used in qualitative approaches are narrative, phenomenology, ethnographies, grounded theory studies and case study. Quantitative approach is the process of analysis and examination of results, produced by the experiments or surveys. The methods used in quantitative approaches are experiment and survey. To answer the research questions we will be using a mix of both approaches, i.e. both the qualitative and quantitative approaches are used. In the qualitative approach, a literature review will be used to collect and analyze related work. The review primarily targets research publications and documents by Trafikverket related to train traffic management and traffic performance analysis. The research publications are collected via databases like INSPEC, IEEE, Google Scholar, Springer Link and ACM Digital Library. In the quantitative approach, an experimental method will be used. Experimental methods are widely used method for statistical analysis and interpretation. The research process of our thesis work is illustrated in Figure 2. It involves three phases, which are discussed below.

Phase 1: Literature review

- Collection of train traffic attributes from literature.
- Analysis of collected attributes mentioned in literature.
- Motivation behind the selection of the most relevant attributes to be used in the benchmark.

Phase 2: Implement and evaluate the use of the selected attributes

- Find or define the formulas for computing the values for the selected train traffic attributes.
- Based on the computed attribute values for the given solutions, benchmark the solutions.
- Visualize the benchmark values and pair-wise comparison of re-scheduling solutions.

The feedback loops in Figure 2 show that the implementation and assessment is an iterative process where e.g. the set of attributes may need to be revised or the formulas may need to be modified or implemented differently.

Phase 3: Results and discussions

- The literature review and the experiments result in a defined set of relevant train traffic attributes to consider in a benchmark of different solutions in real-time train traffic management. Furthermore, observations from the experimental use of the investigated quantitative approach to benchmark solutions based on the selected attributes are made and discussed. The alternative solutions and their pair-wise comparison are demonstrated to the user of the “EOT GUI+” for investigating the solutions, which is done by the “EOT GUI+”.
- Evaluation of the benchmarking procedure and analysis of its limitations are done.
- Future work and improvements are proposed and discussed.
1.3.3 Motivation of Choosing Research Methodologies

The choice of appropriate research methodologies to address each of the research questions are motivated and explained in the below table.

Figure 2. The research process.

1. Literature review
   a. Collection of train traffic attributes.
   b. Analysis of collected attributes.
   c. Motivation of selecting attributes.

2. Implement and evaluate the use of the selected attributes
   a. Definition of formulas and computation of the attribute values.
   b. Benchmark of alternative solutions.
   c. Visualization of pair-wise benchmarked solutions.

3. Results and discussions
   a. Decision-support system for analyzing and benchmarking alternative re-scheduling solutions.
   b. Evaluation of the benchmarking procedure and analysis of its limitations.
   c. Future work.
Research Questions | Research Methodology
--- | ---
RQ1 | A literature review is conducted to find the relevant attributes required for benchmarking different solutions in real-time train traffic management. By collecting, analyzing and comparing the objectives, performance indicators and preferences most frequently used by the research community working on decision support for train traffic management as well as the main stakeholder, Trafikverket, the review will result in a list of relevant attributes to use.

RQ2 | The formulas for computing the selected train traffic attribute values that are found in the literature are analyzed with respect to their adaptability and relevance, the formulas may be included, modified or re-defined. The formulas are applied on a set of sample solution instances during the experiments and the results are analyzed. Hence, the question is answered by the literature review in combination with the experimental assessment.

RQ3 | The dispatcher role and its tasks are analyzed along with the functionalities provided by the STEG graph. Results from the STEG project based on documentation from the same project are also studied. Furthermore, the “EOT GUI” is analyzed in relation to the necessary enhancement features for demonstration. The suggested enhancements are implemented to visualize the pair-wise comparison of any two alternative re-scheduling solutions.

RQ4 | To analyze and benchmark the solutions based on the attributes, experiments are conducted. Any two sample solutions to a common disturbance problem are loaded in the “EOT GUI+”, the attribute values are computed and compared to assess which of the two solutions is the best. The outcome of the benchmark is evaluated and analyzed.

Table 1. Mapping of Research questions and Research methodologies.

### 1.4 Expected Outcome

The outcome of the literature review is a collection of train traffic attributes. The relevance of collected attributes is investigated and most relevant ones are selected to consider in a benchmark of different solutions in real-time train traffic management. Furthermore, observations from the experimental use of the investigated quantitative approach to benchmark solutions based on the selected attributes are made and discussed. The alternative solutions and their pair-wise comparison are demonstrated to the user of the “EOT GUI+” for investigating the solutions further.
2 TRAIN TRAFFIC DISPATCHING

In Sweden the network and train traffic is currently displayed on computer screens and on large distant panels (the large black screen in Figure 4), which is monitored by the train dispatcher. The train dispatcher monitors the train movements and by automatic [35] and manually blocking it controls the train routes. The train dispatcher interferes with the train traffic when there is a disturbance in the train routes this is called “control by exception” [1]. Having the track of the train paths by the train dispatcher, the expected disturbances can be prevented by called so “management by awareness” [4]. The workplace of Swedish train traffic dispatchers are shown in the Figure 4 which is taken from the STEG project [20]. As a support the dispatchers also have a paper document showing the timetable for the relevant stretch and the current day and time [33]. When disturbance occurs, the timetable needs to be revised by drawing new train slots into the time-distance graph printed on a paper. In current train traffic dispatching [31] there is no efficient way of communicating the updated train traffic plans with the train drivers.

The structure of today’s traffic control system in Sweden is depicted in Figure 3. Train dispatchers interact with the train traffic control system [2] through a user interface. The main tasks of the dispatcher [23] are as follows:

- The train dispatchers re-schedule the traffic by drawing time-distance graph in a paper.
- They observe and control the train routes by remote blocking. Remote blocking is done automatic or manual in order to avoid collision between the trains. The usage of track is controlled by the automatic control system for each station.
- They also communicate with drivers.

![Figure 3. The structure of today’s traffic control system in Sweden [35].](image)

In today’s traffic control system there is no decision support system to assist dispatchers to solve the (a) conflicts or (b) to estimate the effects of their alternative solutions. There are challenges dispatchers have conceptually with the fast changing environment and it is important to fast find good solutions which are going to be discussed in following paragraphs.

The dispatcher collects traffic information from several sources. They have time-distance graph as one way of following the traffic. Modified time-distance graph with pencil is used for planning and
documentation. If the network is congested and the workload of the dispatchers is high, then the time is too short to find the new traffic plan. This problem increases the cognitive work load [20]. One of the dispatcher tasks is to find an optimal solution within the time provided or good solution under the time pressure, when the disturbances occur in the traffic plan [23]. There is no decision support system to assist the dispatcher to find optimal solution within the time provided.

Train traffic controlling is a very complex and dynamic work. Therefore, the train dispatcher systems have crucial tasks to perform. To get a whole view of the current train traffic situation, dispatchers need to interact with multiple systems. This is the main problem for train dispatchers since it takes very long time for their decision-making on train traffic timetables. Many times the train dispatchers are in lack of some information for understanding the current traffic situation. So they are assuming own understanding based on the mental models which refer to mostly imaginative and dynamic models that we use in everyday life to think about the world [42]. Disturbances to the trains are frequent, and the dispatchers have to handle the situation. Information about train deviations is not handled efficiently with the provided system [1]. There is no effective decision support system to assist the dispatcher to handle the disturbances of train traffic.

Train dispatchers need to get remembered with large quantity of information regarding continuous change in train traffic. During decision-making different solutions need to be analyzed simultaneously, this is not available today. This situation leads to increase of high load of work for dispatchers to remember the lot of information during dispatching process. Basically, humans have problems to take a decision when they did not look at the situation in real-time [1]. There is no decision support system to assist the dispatcher to estimate the effects of their alternative decisions.

The STEG researchers think that dispatchers should have a decision support system and how they should work with the STEG-graph is going to be discussed in the following paragraphs.

Train dispatchers should have a decision support system which helps during re-scheduling. Decision support system should analyze different solutions simultaneously [1]. It should also support them to solve complex traffic problems [42]. The time-distance graph is the basic structure of train traffic scheduling [24] where the dispatcher does re-scheduling by using timetable lines. The time-distance graph should illustrate the timetable and already scheduled track usage for each train in the network. Information about the attributes notifying deviations need to be indicated in the time-distance graph and attributes which can help the dispatcher to identify the status of the process is needed to be visualized clearly.

The dispatchers should make instant decisions during the train traffic. The dispatchers’ decisions can counteract with the automatic systems, because the plans are not automatically inserted into the system. This situation is referred to as automation surprises [5]. In this situation dispatchers are forced to take the manual decision for conflicted traffic plan, this execution of manual commands may also cause unnecessary problems. The probability of human failure in supervising an automation process increases when the dispatchers are not in alert to look over the status of automation [7]. Automated process used in today’s train traffic may conflict with the train dispatcher wishes, and the automated decision must be switched off during disturbed occasions. Then the train traffic is executed manually. “To improve the train dispatcher’s work during disturbed situations we suggest that autonomous automates that chooses track usage and at the same time reserves train routes should not be used any more” [23].
In the above discussions we have mentioned the term *time-distance graph*. Figure 5 shows an example of a time-distance graph, where typically the x-axis shows the time dimension and the y-axis shows the stations along the railway line of stations which. The lines moving diagonally across the graph show the scheduled trips [27] of different trains. The graph is an important visualization support for the traffic dispatchers both in terms of showing which traffic to expect on the line, and to draw new lines (i.e. trips) when disturbances occur.
3 LITERATURE REVIEW

The literature review accomplishes following purposes. “It shares with the reader the results of other studies that are closely related to the one being undertaken. It relates a study to the larger, ongoing dialogue in the literature, filling in gaps and extending prior studies” [29]. In our thesis literature is presented as a review of the literature. The literature related to our thesis is studied in this process to answer the research questions.

3.1 Source Selection

3.1.1 Key Words

First step is to identify the key words, useful in locating materials in databases. These key words are applied to title and abstract of the literature. The key words are as follows,

- Train traffic
- Disturbance management
- Train delay
- Train traffic dispatching.

3.1.2 Database Chosen

By having the key words in mind, next step is to choose computerized databases for searching literature. We searched literature in following databases,

- INSPEC
- IEEE
- Google Scholar
- Springer Link
- ACM Digital Library

Figure 6. Database selection.
Finally our selection of databases are INSPEC and IEEE. We found many publications related to our thesis in the INSPEC and IEEE databases.

3.1.3 Inclusion Criteria for Literature

- Publications that are in the context as “re-scheduling/dispatching trains” and therefore the attributes they use to assess a re-scheduling solution probably are more relevant while other publications which perhaps are looking at the performance of the complete railway system the past year and tries to compute the socio-economic loss/cost.
- The research work done by STEG group researchers, EOT researchers and the other researchers who prominently proved their work in train traffic, and related areas are included.
- The title and abstract of the literature is analyzed and included if it is related to the research questions.
- The literature which is related to our research area. The main research area is all about train traffic dispatcher problems.
- The literature that has full access to the content is included.

3.1.4 Data Extraction Criteria

The data coming under following category is extracted and analyzed for generating knowledge related to our research.

- Study type
  - Theoretical
  - Experimental
  - Real-time implementation
- Train traffic attributes
  - The attributes are the key performance indicator for the train traffic. The attribute values are used to compare the different solutions and to choose best one. Example: Train delay.
- Train traffic dispatching systems
  - The dispatching system for train traffic is to display the time-distance graphs of the traffic plan and also to deal with the train traffic dispatcher problems.

The Abstract of the literature is read and then they are classified under the above data extraction criteria. The data related to the research question is extracted.

3.1.5 Literature Review Criteria

Literature review is conducted by following criteria,

- Title of the paper
- Objectives of the paper
Train traffic dispatching systems or models are discussed in the paper
Train traffic attributes discussed in the paper
Scenarios and attributes dealt problems discussed in the paper
Conclusions about the attributes in the paper

3.2 Discussion of Review Results

In Aspects of improving punctuality in Sweden railways [32], the improvement of punctuality is mainly discussed. The delay defined in the paper as “the train deviation compared to the timetable”. The actual running time of a train is explained in this paper. The Figure 8 provides details of the running time of a train.

The actual running time is divided into timetabled running time and delay. The timetabled running time consists of basic running time, traffic-dependent time and allowance. The basic running time is the shortest time to travel in the provided section of line. The traffic-dependent time is the time that added to the timetable for passenger exchange at station, as well as train meetings and overtakes (can also be said as buffer time). The buffer time is the time that added to hold on the train in particular railway station or in section of line to overtake by other trains. An example for buffer time: In Karlshamn (Blekinge, Sweden) station the öresundståg from köpenhamn to karlskrona has to wait for 5 minutes (There are trains for every 1 hour) because the train from karlskrona to köpenhamn has to arrive the karlskrona station (from opposite), then only the train to karlskrona have to move on the track (Note: It is a single line track). Allowance time (buffer time) is added to the basic running time or traffic-dependent time to serve as recovery time and also to prevent or reduce the delay.

Höjer [19] defines time lost as “time lost = actual running time - basic running time”, by subtracting basic running time from actual running time the result gives the time lost which means delay. The delays are categorized into primary delay and secondary delay is depicted in the Figure 8. “A primary delay to a train is a delay that directly strikes that particular train and a secondary delay is a delay caused by another train’s deviation from the timetable”. The primary delay [13] cannot be recovered in real-time by train traffic, it is an unavoidable delay. The primary delay affects the other trains in the network. This may cause consecutive delays is called knock-on delay or secondary delay [13]. It may be arrival delay, departure delay or, etc. The secondary delay can be recovered by train dispatchers through re-scheduling the timetable. While considering secondary delay, the delay of one train inflicts the other trains. The aim of the analysis is to achieve the punctuality and efficiency in the traffic flow.

Figure 8. Categorization of slot time components including delay types [19].
An information and decision support system for railways traffic control [30] is suggested in this paper. MINT (Manager of Integrated Networks of Train Traffic) is a system which uses the information management and decision-support functions to assist railway traffic controllers in their work. Many different alternative attributes are considered for minimizing delays in strategy. The discussed attributes are “(i) the sum of all delays; (ii) The weighted sum (with the train categories) of all delays; (iii) the sum of the square of the (weighted) delays; (iv) the maximum lateness and (v) the maximum lateness of a selected category of trains”. Among the attributes, the weighted sums of all delays (ii) are mainly considered as the goal function to minimize. In this paper a scenario is generated and two different solutions are proposed for the selection of better one. The problem is fast train reaching a slower one. The possible solutions are (i) Fast train is slowed down and to let go the slower trains (ii) Slower trains are stopped on the track, until the fast train overtakes the slower train. A solution is selected on the basis of the attributes discussed in first. Stopping the slower train works better, because the train category got more prioritized in this case. Hence the attributes plays the important role to select a solution from the railway traffic timetable and also this paper gives the idea of attributes to be used to compare two different solutions.

A computerized train dispatching system [11] called ROMA (Railway traffic Optimization by Means of Alternative graphs) is developed for the train traffic controllers to dispatch the solutions. The main goal of this dispatching system is to minimize the consecutive delays. Indirectly it implies the number of trains that are delayed before and after railway traffic. ROMA also computes a dispatching solution that optimizes train delays. The train delay is calculated in terms of time units. Hence the number of trains and train delay are the attributes discussed here.

Decision making strategies for intelligent control system of Train speed and train dispatch in Iran Railway [21] are proposed in this paper. To design a fuzzy control system for controlling of dispatching trains three attributes are considered. They are Priority of trains, amount of delay (deviation from the train timetable) and compulsive stop (Number of compulsive stops during the whole travel of the train). The train delay is categorized into two delays, 1) delay at station & 2) delay en route. The above attributes are considered and discussed in this paper for making decision to dispatch trains.

Bicriteria train scheduling for high-speed passenger railroad planning applications [46] objective is to minimize both (i) the expected waiting times for high-speed trains and (ii) the total travel times of high-speed and medium-speed trains. The application concentrates to minimize overall operational costs and also to satisfy passenger and freight traffic demand.

In railway traffic disturbance management [38], a performance evaluation on various railway traffic attributes are performed. HOAT, a heuristic approach is used for allocating tracks to trains (modifies initial timetable) after disturbance to the trains. The attributes considered during the analysis are total final delay, total accumulated delay, total delay cost and total number of trains delayed. The objective of the experiment is to minimize the above attributes. Total final delay is the sum of delays at the end of the train destination, while total accumulated delay is the sum of all delays counted at the each delay event. Total delay cost is the delay cost that the train experiences during the trip and to final destination. Total number of trains delayed refers to the trains that reach the final destination with the delay greater than zero. A performance evaluation is done by solving 40 scenarios, each scenario is solved by HOAT (track is assigned to train when disturbances is occurred) approach. The objective is to minimize the total final delay and total accumulated delays for the scenarios considered for this evaluation. Graph is drawn for the solved scenarios for all attributes considered. Finally the paper is concluded with the minimization of total accumulated delay tends to delay more trains than the minimization of total final delay or total delay costs.

The modelling of train delays and delay propagation at train stations are discussed to improve the capacity utilization of timetable in Netherland [45]. Arrival delay, dwell times and departure delay are the delay attributes discussed in this paper. The arrival delay is defined as the difference between the arrived time of train to the station and the scheduled time of train at the station. Dwell time is the
difference between the arrival time and the departure time. The departure delay is the difference between the actual and the scheduled time of a train gives the departure delay.

In Computer-based decision support for railway traffic scheduling and dispatching [36], a detailed comparison of the various approaches for railway traffic scheduling is made. A differentiation is made between tactical scheduling, operational scheduling and of railway traffic. The framework is applied to classify the problem type, control strategies, problem formulation, solution mechanism and problem instance and size.

Törnquist [37] designed an effective algorithm to find the railway traffic solution in fast response. A greedy algorithm is developed to retrieve a feasible solution which performs a depth-first search using an evaluation function. The author’s main aim is to provide good solutions to the railway traffic disturbance management problem within reasonable time.

A branch and bound algorithm for scheduling trains in a railway network [12], this paper studies about a train scheduling problem which is faced by traffic managers in a real-time environment. The main objective of this algorithm is to minimize the maximum secondary delay for all trains. The maximum secondary delay is the maximum delay of a single train before re-scheduling the traffic problem. Hence, the attribute extracted from this paper is maximum secondary delay (can be said as maximum lateness).

D’Ariano [13] investigated the new concept of flexible timetable which improves the train punctuality of real-time railway management. Recovery time is introduced to reduce to time delay between the trains. The evaluation of three principles is made separately in a single case study and there is need of testing these principles simultaneously on different timetables.

In Knowledge-based system for railway scheduling [9], the priority is given to fastest passenger trains and lowest to cargo trains. The system is mainly for the Taiwan railways, in which “passenger’s degree of satisfaction toward service” we can take in terms of robustness and “operation cost” are mainly considered attributes.

Robustness in Railway Transportation Scheduling [34], this paper proposes some guidelines to measure robustness in timetabling. A formula is proposed to compare robustness between two re-scheduling solutions. This comparison is mainly dealt with the buffer times, robustness increases when the buffer time increases. The result of comparing robustness between two re-scheduling solution shows that the percentage of robustness is increases when the maximum delay decreases. Hence, maximum delay (can be said as maximum lateness) and robustness are the two attributes used in this paper for discussion.

Robustness is one of the attributes which is considered for comparing two solutions. Robustness refers to “the ability to resist to imprecision” [34] or “cope with unexpected troubles without significant modifications” [44].

Robustness in Sweden Railway Traffic Timetables [3], describes how to compute the margin and to include it to train timetable. Margin refers to extra time that is added to running time in a timetable. In this paper, a case study is made to analyze the regular time delay of a train from Stockholm to Malmö. After analysis they found some regular delays, hence by finding these delays margin time is added to train timetable to get robustness.

A conclusion is made on the analysis of margins; margins need to be flexible and cost-effective because the need for margin depends on the conditions of the railway network. The margin time is also said to be buffer time in some of the train traffic implementations [32].

DeWilde [14] defined robustness of a railway timetable. This paper presents a generic definition of robustness of a railway timetable against small delays and also measured the robustness of the current
schedule. The objectives which have used are minimizing the average delay, minimizing the percentage of missed transfers, minimizing the settling time, minimizing the passengers’ delay and optimizing transfers. The two different types of extra scheduled times used in this paper are supplements and buffers, whereas supplements provide more time for a train to complete its itinerary and buffers provide more spacing between two consecutive trains.

In railway dispatch planning and control [41], an analysis of train movements using fuzzy set techniques and to help the train dispatcher is discussed. They have addressed the issue like the computer system may not have full information about the objective that dispatchers may perform. Author says that the computer-aided system should accept constraints via an appropriate man machine interface. The dispatchers have shifted from a pencil and paper procedure to a computer based decision support system.

Research on the model of the dispatching system of the industrial railway based on GWFN [17], in this paper dispatching system with the interlocking part for the industrial railway was designed. The objective of the dispatching and controlling system is (i) the interlocking system performs controlling based on the dispatching plan automatically and (ii) the transportation plan can be made and transform to the interlocking system automatically. This paper helps us to know about the traffic dispatching system works in real-time environment.

This chapter has summarized the collection and analysis of the objectives, performance indicators and preferences most frequently used by the research community working on decision support for train traffic management. Table 2 below summarizes the resulting set of attributes and the chosen definitions, while Table 3 presents which publications that have addressed the corresponding attributes. The left column in Table 3 contains the reference to the publication, and the first row contains the selected acronyms of the attributes that are already defined in Table 2. An “X” indicates that the work described in the corresponding publication somehow addresses or applies the given attribute. The relevance of each attribute can consequently then be further analyzed based on the frequency of X:s. In the following chapters, the set of attributes is analyzed further based on the results in Table 3, the viewpoint and strategies of Trafikverket as well as based on the experimental assessments.
<table>
<thead>
<tr>
<th>No.</th>
<th>Attribute</th>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>1</td>
<td>Total final delay</td>
<td>TFD</td>
<td>The sum of the final delay of the trains at their final destination [38].</td>
</tr>
<tr>
<td>2</td>
<td>Total accumulated delay</td>
<td>TAD</td>
<td>The sum of train delays that occur at each event [38].</td>
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<tr>
<td>3</td>
<td>The weighted sum (with the train categories) of all delays</td>
<td>WD</td>
<td>The sum of delays within the trains’ categories [30].</td>
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<td>4</td>
<td>Delay en route</td>
<td>DR</td>
<td>Any positive deviations that occur en-route with respective to the timetable.</td>
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<tr>
<td>5</td>
<td>Delay at station</td>
<td>DS</td>
<td>Any positive deviations that occur at station with respective to the timetable.</td>
</tr>
<tr>
<td>6</td>
<td>Arrival delay</td>
<td>AD</td>
<td>The difference between re-scheduled arrival time and the scheduled arrival time of a train at the station [45].</td>
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<td>7</td>
<td>Dwell time</td>
<td>DT</td>
<td>The difference between the arrival time and the departure time of a train at the station [45].</td>
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<tr>
<td>8</td>
<td>Departure delay</td>
<td>DD</td>
<td>The difference between re-scheduled departure time and the scheduled departure time of a train at the station [45].</td>
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<td>9</td>
<td>Average final delay</td>
<td>AFD</td>
<td>The average of all the final delay in the train traffic network.</td>
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<td>10</td>
<td>Maximum Lateness</td>
<td>ML</td>
<td>The maximum final delay from the re-scheduled timetable by considering all trains.</td>
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<td>11</td>
<td>Total number of trains delayed</td>
<td>TND</td>
<td>The number of trains that reach the final destination with a delay larger than X minutes.</td>
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<td>12</td>
<td>Total delay cost</td>
<td>DC</td>
<td>The sum of all delay costs that the trains experience [38].</td>
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<td>13</td>
<td>External unpunctuality cost</td>
<td>EC</td>
<td>The external unpunctuality cost [32] is the cost, which affects the stakeholders outside the railway sectors. For example: Industries are affected because of unavailability of raw materials at the right time due to delay of freight trains.</td>
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<tr>
<td>14</td>
<td>Internal unpunctuality cost</td>
<td>IC</td>
<td>The internal unpunctuality cost [32] is the cost, which affects inside the railway sector.</td>
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<td>15</td>
<td>Failure cost</td>
<td>FC</td>
<td>The cost that needed to compromise the delay that happened due to failure of a train.</td>
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<tr>
<td>16</td>
<td>Maintenance cost</td>
<td>MC</td>
<td>The cost that needed for maintenance of the train.</td>
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<tr>
<td>17</td>
<td>Penalty cost</td>
<td>PC</td>
<td>The cost for compensating passengers experiencing a train delay of minimum 30 minutes [38].</td>
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<td>18</td>
<td>Robustness</td>
<td>R</td>
<td>A robust timetable must be able to deal with a certain amount of delay without traffic control intervention. Timetable robustness therefore determines the effectiveness of schedule adherence after disruptions [16]. Robustness is also important to consider in the re-scheduled timetables/solutions.</td>
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<tr>
<td>19</td>
<td>Buffer time</td>
<td>BT</td>
<td>The waiting time of trains at each station and route, i.e. allowance as indicated by Figure 8.</td>
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Table 2. Definition of attributes.
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Table 3. Related Research.
From the review of related research, we collected various train traffic attributes used by the author’s in the publications. In publications, author’s objectives were to minimize the delays, minimize the cost, minimize the number of delayed trains and maximize the robustness. The measurement attributes which mainly considered for train traffic are time delay (time units), cost (required to maintain the punctuality), number of trains delayed and robustness (based on basic or dynamic priority of the train). The time delays can be in various forms; they are sum of all delays (accumulated delays), total final delay, maximum lateness, arrival delay, dwell time and departure delay.

The attributes from the Table 2 are briefly analyzed in chapter 4 “Analysis of Attributes”. Analysis of attributes includes the definition of the attribute, formula for computation; if necessary a time-distance graph is drawn to explain the attribute and motivations of the attribute is given, why it was not considered further selection.
4 ANALYSIS OF ATTRIBUTES

The concept of using attributes is to assess the re-scheduling solutions and to quantitatively benchmark the alternative solutions. There are many attributes that can be interesting and compared but in a real-time environment too much information can become a problem so only the most relevant and dominating ones are of interest here. In the reviewed research publications, attributes related to delays, costs and robustness attributes are most frequently discussed and in this chapter we will focus on these. In this chapter, we go into more detail by giving a clear definition of each of the selected attribute and investigating suitable formulas and data requirements for these. In Chapter 5, we make the final selection of attributes to implement and use in the experimental assessment.

Attributes are analyzed by using the following steps,
- Attribute is defined.
- Attribute is explained by using a simple time-distance graph.
- Attribute is motivated to use.
- Formula to compute the attribute is defined.

Below we outline a scenario to exemplify how two re-scheduling solutions may differ structurally and how attributes can be used to assess and benchmark them. The stretch Mjöby-Katrinholm (illustrated in Figure 9) is part of the Southern main line (in Swedish: Södra Stambanan). The fast passenger trains to/from Stockholm run via Katrinholm and Flen and the slower passenger trains run via Nyköping. Mjöby, Linköping, Norrköping and Katrineholm are major connection points for certain trains that have a scheduled stop. The stretch Katrineholm to Mjöby is double-tracked while the stretch north of Åby is single-tracked.

![Figure 9. A part of the Swedish railway network [38].](image-url)
**Scenario:**

Figure 10 shows the initial timetable for the railway line between Mjölby and Kolmården. It circles the conflict that arises due to that the two trains (204 and 550) cannot run as normally in parallel on the double-tracked section. Therefore, the timetable is re-scheduled to avoid the conflict between the trains.

Solution A - There are two trains, numbered 204 and 550, from Mjölby to Kolmården, which has 10 minutes and 4 minutes delay respectively. The graphical representation of solution A is depicted in Figure 11.

Solution B - Only one train, 204, is delayed on the route from Mjölby to Kolmården. The delay is 24 minutes. The graphical representation of this Solution B is depicted in Figure 12.

![Figure 10. Graphical representation of conflicted timetable scenario.](image-url)
If analyzing both solutions, see Figure [11, 12], and deciding that the total train delay is the dominating attribute, the conclusion is that solution A is better (14 minutes) than solution B (24 minutes). However, since solution B has only 1 delayed train while solution A has 2, the conclusion could be questioned. That is, if another prioritization would be made and/or other attributes would be considered, the outcome could be different.
4.1 Train Delays

In our thesis a delay of a train refers to that “the train deviations compared to the timetable” [32]. The train deviations may be in positive or negative values. Any positive deviations that occur in its journey with respective to the timetable are called delay [22]. The negative deviation of a train from the timetable is called lead. The term “delay” can be said as “train delay” which is defined in “Efficient scheduling of railway traffic based on global information of train” [28] as Train delay is positive deviation from the planned schedule. The train delay is measured in time units, usually minutes. “Bob railway case benchmarking passenger transport in railways” [8] discusses in brief about train delay. The delay of the train is allowed to 3, 5 or n minutes is discussed in various cases. The long-distance train can be delayed to 5 minutes because of the long-distance travel can be interrupted by many short-distance trains. While considering short-distance train even greater than 3 minutes is considered to be delay because the short-distance traveler will expect the train to reach in time. There is also risk in delaying the train, many passengers has to catch their connection train to travel to different place. So if the travelling train is delayed than the passenger cannot able to catch the connection train. The tolerance of the delay among different countries [32]; the tolerance is one minute(for Japan), two minutes (for Denmark), three minutes (for Netherland, Austria, Norwegian Nsb local and Australia local), five minutes (Norway Nsb long-distance, Finland and Switzerland), 10 or 15 minutes(GB), 30 minutes (for Australia freight). The tolerance level of the delay for Sweden trains is within 5 minutes [6].Finally we have chosen the tolerance level of train delay may be greater than 5 minutes (TD5+) and train delay greater than 1 minute to lesser than or equal to 5 minutes (TD1+).

The conditions are
- TD5+ (>5 min)
- TD1+ (>1 min to ≤ 5 min)

The maximum final delay from the re-scheduled timetable by considering all trains is called maximum lateness. The aim of the train dispatcher is to reduce the maximum lateness that will occur due to delay. While considering the delay of a single train, the maximum lateness can be said as maximum delay. Hence, the maximum delay of a single train is considered as an attribute when comparing the alternative re-scheduling solutions.

Delay can be categorized in too many delay sub-attributes; there are many sub-attributes which also cover under the Delay. Many researches has been undergone to find all delay attributes that affects the delay, from those research some the sub-attributes of the delay are considered here to compare the alternative re-scheduling solutions.

The train delay sub-attributes [38] are:
- Total final delay
- Total accumulated delay

Figure 13 is the simplified time-distance graph to represent the running time of the train which is going to be used in the following sections. Initial arrival time (IAT) is the initially scheduled time for the train to arrive at any event. New arrival time (NAT) is the re-scheduled time for the train to arrive at any event i.e. arrival time in the re-scheduled timetable. Initial departure time (IDT) is the initially planned time for the train to depart from any event. New departure time (NDT) is the newly planned time for the train to depart from any event i.e. new departure time in the re-scheduled timetable. Train A and Train B are the initial schedules for the trains and Train A’ is the re-scheduled train. These notations can be clearly seen in the below figure.
4.1.1 Train Delay

Any positive deviations that occur in its journey with respective to the timetable are called train delay. Train delay (TD) is measured in minutes. The below figure depicts the time-distance graph for train delay.

\[
\text{Train Delay (TD)} = \sum_{i=1}^{n} \left\{ \sum_{k=1}^{m_i} \max (0, ((\text{NAT})_k - (\text{IAT})_k)) \right\}
\]

The suffix variable \(i\) is used as an index for train \(i\) in the set of \(n\) number of trains, i.e. \(i \in \{1\ldots n\}\) and \(k\) is used as an index for event \(k\) in the set of \(m_i\) events of train \(i\), i.e. \(k \in \{1\ldots m_i\}\).

4.1.2 Total Final Delay

“The sum of the final delay of the trains at their final destination” [38]. The below figure indicates the total final delay (equals to final delay in this case), since only one train has final delay greater than \(X\) minutes.
The formula to calculate total final delay is,

\[
\text{Total final delay (TFD)} = \sum_{i=1}^{n} \left\{ \sum_{k=1}^{m_i} (\max [0, ((NAT)_k \text{ at final destination} - (IAT)_k \text{ at final destination})]) \right\}
\]

The suffix variable \(i\) is used as an index for train \(i\) in the set of \(n\) number of trains, i.e. \(i \in \{1 \ldots n\}\) and \(k\) is used as an index for event \(k\) in the set of \(m_i\) events of train \(i\), i.e. \(k \in \{1 \ldots m_i\}\).

**4.1.3 Total Accumulated Delay**

“The sum of train delays that occur at each event” [38]. Total accumulated delay covers the arrival delay and departure delay at each station, which is discussed in this chapter. The formula to calculate the total accumulated delay is,

\[
\text{Total accumulated delay (TAD)} = \sum_{i=1}^{n} \left\{ \sum_{k=1}^{m_i} \max [0, ((NDT)_k - (IDT)_k)] \right\}
\]

The suffix variable \(i\) is used as an index for train \(i\) in the set of \(n\) number of trains, i.e. \(i \in \{1 \ldots n\}\) and \(k\) is used as an index for event \(k\) in the set of \(m_i\) events of train \(i\), i.e. \(k \in \{1 \ldots m_i\}\).

**4.1.4 Delay en Route**

Any positive deviations that occur en route with respective to the timetable are called delay en route. The delay en route is covered in the accumulated delay. So, delay en route attribute is not considered.

**4.1.5 Delay at Station**

Any positive deviations that occur at station with respective to the timetable are called delay at station.

**4.1.6 Delay Propagation in Stations**

Punctuality of a train is calculated based on the percentage of trains passing, arriving to the station or departing from the station according to the scheduled time in minutes. Hence the following delays are considered in discussion [45].
(i) Arrival delay
(ii) Dwell time
(iii) Departure delay

4.1.6.1 Arrival delay
The arrival delay [45] is the delay that can be defined as the difference between the arrived time of train to the station and the scheduled time of train at the station. The arrival of a train to the station may delay due to late departure from previous station, long running time from the upstream station, or the occupancy of another train in the route or the station. There are negative (earlier arrival of train) and non-negative (on-time or late arrival of train) arrival delays. However negative delays will not affect the punctuality level but may lead to less efficiency of station utility. The below figure indicates the arrival delay.

![Figure 16. Arrival Delay.](image)

The formula to calculate the arrival delay (AD) is,

\[
Arrival\ delay\ (AD) = \sum_{i=1}^{n} \{ \sum_{k=1}^{m_i} \max(0, ((NAT) at each station – (IAT) at each station)) \}
\]

The suffix variable \(i\) is used as an index for train \(i\) in the set of \(n\) number of trains, i.e. \(i \in \{1...n\}\) and \(k\) is used as an index for event \(k\) in the set of \(m_i\) events of train \(i\), i.e. \(k \in \{1...m_i\}\).

4.1.6.2 Dwell time
The dwell time [45] is the time that the train waiting at the station, the difference between the arrival time [15] and the departure time. The dwell time may be 1, 2 or 3 min according to the schedule. The dwell time depend on the train type, size of the station and also based on the connection train transfer. The dwell time resembles the delay en station attribute. So, this attribute is also not considered.

4.1.6.3 Departure delay
The departure delay [45] is the delay that the train may leave the station in late, the difference between the departure and the scheduled time of a train gives the departure delay. The departure delay happens due to late arrival of the train to the station and long waiting time (dwell time) in the station. The below figure indicates the departure delay.
The formula to calculate the Departure time (DD) is,

\[
\text{Departure delay (DD)} = \sum_{i=1}^{n} \left\{ \sum_{k=1}^{m_i} \max (0, ((NDT)_{i,k} - (IDT)_{i,k})) \right\}
\]

The suffix variable \( i \) is used as an index for train \( i \) in the set of \( n \) number of trains, i.e. \( i \in \{1\ldots n\} \) and \( k \) is used as an index for event \( k \) in the set of \( m_i \) events of train \( i \), i.e. \( k \in \{1\ldots m_i\} \).

Decision making strategies for intelligent control system of Train speed and train dispatch in Iran Railway [21], discusses the delay en station and delay en route. The delay en station is clearly discussed in above parts i.e. the arrival delay, departure delay and dwell time. The delay en route indicates the train need to be stopped in the middle of his track path due to the previous train delay or may be that the train has to wait for the track change. Departure delays can also be influenced by the passenger flows on the platforms as well as how passengers enter and leave the trains [12].

### 4.1.7 Average Final Delay

The average of all final delays that happens for the particular situation, there may be \( n \) number of trains which is delayed. Every train may delay by various time gaps. By finding average for all final delays gives the average final delay [13]. The branch and bound algorithm [12] exhibits better optimal solution when considering the average final delays rather than other delay attributes. The formula to calculate the average final delay for a single re-scheduling solution is,

\[
\text{Average final delay (AFD)} = \frac{[\text{TFD5+}] + [\text{TFD1+}]}{\text{TND}}
\]

In the above formula, TND refers to the total number of delayed trains.

### 4.2 Number of Delayed Trains

The number of delayed trains is the total number of trains that are delayed at their final destination i.e. TD>0. When the comparison is made between alternative re-scheduling solutions the tolerance level for train delay is TD5+ and TD1+ in our case for considering the number of delayed trains.

This attribute is necessary to consider because due to single train delay, consecutive delays may occur. Due to re-scheduling single train, many trains may deviate (positive) from the timetable and may cause delay. Therefore the number of delayed trains is considered when selecting best solution.
There is however risk, when the number of delayed train is considered. Consider a scenario, where solution A has 10 number of trains are delayed and Solution B has 5 number of trains are delayed. But the total number of passengers travelled in 10 trains (in solution A) is lesser than the total number of passengers travelled in 5 trains (in solution B), then the consideration of this attribute-Number of delayed trains fails. Delay assessment [32] discussed in Aspects of improving punctuality says punctuality measure for passenger trains should relate to passengers, not trains.

4.3 Cost

The delay cost refers to “the sum of delay costs that the trains experience at their final destination and to some extent also during the trip” [38]. The cost is one of the main attribute to be considered for comparing two re-scheduling solutions. In a literature cost is calculated based on the train types [38], so in our thesis we follow the same idea to calculate delay cost. Cost is the consequences of unpunctuality [32], hence the unpunctuality leads to delay which indirectly affects the cost. “Punctual means in this thesis that one or several events occur when agreed between involved stakeholders” [32].

Statistics from Trafikverket [40]: In 2010, punctuality for passenger trains that arrived at the latest 5 minutes late is 87 per cent when compared to 2009 it is 93 per cent and cancelled passenger trains are 28,847 when compared to 2009 it is 26,030. Since there is decrease in punctuality for passenger train delay and increase in cancelled passenger trains, then delay cost may increase. Hence, cost is considered as one of the main attribute for comparing alternative re-scheduling solutions.

The cost may be of delay cost, external unpunctuality cost, internal unpunctuality cost, failure cost, Maintenance cost and finally penalty cost. The external unpunctuality cost [32] affects the stakeholders outside the railway sectors, the industries are affected due to the unavailable of raw materials at right time due to the delay of freight trains. The internal unpunctuality cost [32] affects inside the railway sector, Training operating Companies (TOCs), Centralized Train Traffic Control offices (CTTCs) and Maintenance Comparators (MCs). Penalty cost [38] is the cost that is needed to be paid by the Railway operators to passengers due to train delay of 30 minutes. Delay cost, unpunctuality cost and penalty costs are considered mainly for the comparison of two re-scheduling solutions, because the failure cost and maintenance costs are cannot be considered when comparing two solutions.

The trains in the Swedish railway traffic system can be categorized into the following train types [38], which can be used to calculate the appropriate train delay cost. There may be other/updated values for delay cost but we have selected this one from Table 4.

- Long-distance high-speed train: Fast passenger trains that travel across different parts of the country at maximum speed of 200 km/h.
- Intercity train: Passenger trains that travel between larger cities similar to the long-distance high-speed trains but operate at a lower speed (160-180 km/h).
- Local commuter train: Passenger trains that travels within a certain city and/or region.
- Fast freight train: Freight trains which may operate at maximum 160 km/h, e.g. the postal trains (Posttägen).
- Low-speed freight train: Freight trains which operate at 70-100 km/h.
- Service train: Trains that transport tools for repair/maintenance or to clear the train paths.
<table>
<thead>
<tr>
<th>Train Type</th>
<th>Train delay cost(SEK/min)</th>
<th>Cargo delay cost(SEK/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-distance high-speed train</td>
<td>194</td>
<td>3 per passenger</td>
</tr>
<tr>
<td>Intercity train</td>
<td>82</td>
<td>2.83 per passenger</td>
</tr>
<tr>
<td>Local commuter train</td>
<td>78</td>
<td>2.17 per passenger</td>
</tr>
<tr>
<td>Fast freight train</td>
<td>32.86</td>
<td>0.85 per tonnes</td>
</tr>
<tr>
<td>Low-speed freight train</td>
<td>35.23</td>
<td>0.06 per tonnes</td>
</tr>
<tr>
<td>Service train</td>
<td>44</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4. Delay cost.

SEK refers to Swedish kronor.

The delay cost calculation is based on the final train delay of each train. Hence the formula to calculate the total delay cost for a re-scheduling solution is as follows,

\[
Total \ delay \ cost \ (TDC) = \sum_{i=1}^{n} \{ \max [0, ((TFD)_i \ at \ final \ destination \ * \ (Delay \ cost)_i)]\}
\]

Delay cost is taken from the Table 4. The suffix variable \( i \) is used as an index for train \( i \) in the set of \( n \) number of trains, i.e. \( i \in \{1…n\} \).

### 4.4 Robustness

Robustness refers to “the ability to resist to imprecision” [34]. A solution is proposed due to the train delay that occurs in original timetable; hence the stable re-scheduling solution is created. Therefore the presence of robustness is required, while comparing two re-scheduling solution robustness is also taken into account. The other definition for robustness is “A robust timetable must be able to deal with a certain amount of delay without traffic control intervention. Timetable robustness therefore determines the effectiveness of schedule adherence after disruptions.” [16]. The timetables with 10 minutes of running time supplement on each trip tend to be robust according to some definitions [14].

Robustness can be measured by using certain parameters [34]. They are as follows:

- **Buffer time**—“Buffer time is the temporal interval in which a train is stopped and it is not carrying out any traffic operation” [34]. The buffer time is the waiting time of a train [18]. The waiting may be in the station or in the route. Mostly buffer time is pre-planned in the train timetable. Below example explains the usage of buffer time in the timetable.

**For example:** Consider the train path from Figure 9. The single-tracked segment from Nyköping C to Järna (leads to Stockholm).

Train A => Nyköping C to Järna (leads to Stockholm)

Train B => Järna to Nyköping C

At some point the train A and train B have to meet between Nyköping C and Järna because it is single-tracked segment. So, the timetable has to be planned such that train A will wait at one station in between the Nyköping C & Järna until the train B crosses the one particular station. Hence the waiting time of the train A is said to be buffer time.

- **Number of trains**—More number of trains in particular railway network causes disruption, so less number of trains implies higher robustness. In general it depends on the ratio tracks by trains.

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• Number of commercial stops- Number of stops where train used to load or unload the passengers in the station. The number of commercial stops is directly proportional to the number of disturbances.

• Flow of passengers- The flow of passengers will be more in main city station, hence the disruption occurs. The railway operators should calculate the disruption probability for each train in each station.

• Tightest track- “The tightest track is the longer distance track” [34]. Tightest track is all about the longer distance track between two stations, the track may be single-tracked segment. Because the train has to wait in station until the train from opposite crosses the longer distance track. So, this obviously increases the buffer time.

The robustness can be measured by using the below formula [34], summing of all buffer times of a timetable x,

\[ R(x) = \sum_{i=1}^{x} b_i \]  (1)

The given timetables are x and y, if R(x) > R(y) ⇒ timetable x will be more robust than timetable y. By using above formula we can predict the robust timetable (re-scheduling solution in our case).

The first analytical method to calculate robustness is as follows

\[ R(x) = \sum_{T=1}^{NT} \sum_{S=1}^{NS} Buff_{TS} * \%Flow_{ST} * TT_{ST} * NSucT_{ST} * \frac{NS-S}{NS} \]  (2)

NT=> Number of trains

Buffers_{TS}=> Buffer time of train T

Flow_{ST}=> Percentage of passenger flow in train T

NSucT_{ST}=> Number of trains that may be disrupted by train T

TT_{ST}=> Percentage of tightness of track between stations S, S+1

S=> Station

T=> Train

The result of the related research is train traffic attributes in the Table 3. There may be numerous attributes which affects the train traffic but relevant attributes to our thesis are addressed and defined in this chapter. The attributes are completely studied and the attributes which are related to our thesis are defined. Some of the attributes have various forms of definitions which imply the same thing. Hence, the suitable definition for our thesis is selected and some of them are modified based on the necessity. The explanations for clarifying the conflict between the attributes are given. Conflicts between some of the attributes are also motivated based on the need.

Finally formulas for computing the attribute values are defined. The considerations among the different attributes are motivated in next chapter.
5 Motivation and Selection of Attributes

This chapter describes motivation of attributes and to select them for further process. The attributes are selected to demonstrate and evaluate benchmarking for alternative re-scheduling solutions. The selected attributes are train delay and its sub-attributes, number of delayed trains, cost and then robustness. These attributes are selected based on the related research Table 3 and also analysis made using the availability of data for calculating the attribute values. The brief motivations of the selected attributes are as follows.

5.1 Train Delays

The tolerance level of train delay is considered with conditions. Train delay greater than 5 minutes (TD5+) and train delay greater than 1 minute to less than or equal to 5 minutes (TD1+). The conditions are

- TD5+ (>5 min)
- TD1+ (>1 min to ≤ 5 min)

Total final delay and Total Accumulated delay attributes are chosen for comparing alternative re-scheduling solutions. The chosen tolerance level for total final delay is TFD5+ and TFD1+. Arrival delays, departure delays, delay en route and dwell time attributes are not considered further because they are included while calculating total accumulated delay. Maximum delay of a single train is calculated to know which train tends to the maximum delayed after re-scheduling a solution. Average final delay is also considered while choosing best solution among alternative re-scheduling solutions.

5.2 Number of Delayed Trains

The status and performance of the railway network are measured and presented in certain ways by e.g. number of delayed trains [38]. When the number of delayed trains is less for a solution then that particular solution is preferred for the best selection, hence this attribute is mainly considered while comparing alternative re-scheduling solutions. Total final delay is considered while calculating number of delayed trains. The total number of delayed trains for condition TFD5+ is denoted as NTFD5+ and the total number of delayed trains for condition TFD1+ is denoted as NTFD1+. The formula for calculating total number of delayed trains for a single re-scheduling solution is,

\[ \text{Total number of delayed trains} = (N_{TFD5+}) + (N_{TFD1+}) \]

5.3 Cost

Total delay cost is considered for comparing alternative re-scheduling solutions. Total delay cost is calculated when the train delay is TFD5+ and TFD1+. Since the details of the cargo trains are not available the cargo delay cost is not considered in our case. The failure cost and maintenance cost is not relevant to consider while comparing re-scheduling solutions. Due to insufficient data penalty cost and unpunctuality cost are excluded from consideration.

5.4 Robustness

The robustness for the solutions can be calculated using equation (2) but due lack of data the robustness cannot be able to calculate. For example Percentage of passenger flow in train T is cannot be determined, because of insufficient data.
The average delay of the trains in a railway system can be improved by looking over the optimal allocation of time supplements and buffer times in the timetable [25]. This re-allocation of buffer times may improve the robustness of a timetable when considering small disturbances [34]. Hence, the buffer time is inserted in train timetable during re-scheduling to assure degree of robustness of the timetable [44].

The buffer time is used to calculate the robustness of a re-scheduling solution in our thesis. The buffer time of each train is calculated as follows.

\[
\text{Buffer time (B) for New timetable = } \sum_{i=1}^{n} \left\{ \sum_{k=1}^{m_i} \left[ \max(0, \{(\text{NAT})_k - (\text{NDT})_k\} - \{(\text{minimum run time})_k\}) \right] \right\}
\]

\[
\text{Robustness (R) = B}
\]

The suffix variable \(i\) is used as an index for train \(i\) in the set of \(n\) number of trains, i.e. \(i \in \{1\ldots n\}\) and \(k\) is used as an index for event \(k\) in the set of \(m_i\) events of train \(i\), i.e. \(k \in \{1\ldots m_i\}\).

Buffer time (B) is calculated by subtracting every minimum run time from the new run time (subtracting new start time from new stop time) for each train. The time taken to traverse a specific train path (i.e. the length of the corresponding event) is the running time [39]. The minimum running time is the computed value, prior to re-scheduling solutions for event \(k\) (an event is the path between stations) [39]. Hence the robustness(R) for a re-scheduling solution is buffer time for new timetable (B).

Let \(x\) and \(y\) are two re-scheduling solutions, if \(R(x) > R(y) \Rightarrow \) timetable \(x\) will be more robust than timetable \(y\).
6 EXPERIMENTS AND RESULTS

In this Chapter, experiments and results of the re-scheduling solutions are discussed briefly. The implementation snapshots of the “EOT GUI+” with the descriptions are also discussed in detail.

6.1 Benchmarking of Alternative Solutions

6.1.1 Purpose and outcome of the experiment
In addition to the theoretical selection of relevant attributes based upon the previous literature review, experiments are conducted. The purpose of the experiments is to investigate how the set of motivated attributes and their formulas responds when applied in a benchmark of a set of sample re-scheduling solutions for different disturbance scenarios. The formulas are implemented in the EOT GUI+ which serves as the tool to demonstrate the benchmark. The aim of the benchmark is to make a quantitative assessment of each re-scheduling solution and then a pair-wise comparison of two alternative solutions. The benchmark is ultimately supposed to result in a recommendation of the most suitable re-scheduling solution. Consequently, the result of the benchmark should give a clear indication of which solution is the best one of the two compared.

6.1.2 Experimental setup
The work procedure of our experiment is as follows. The benchmark framework is set to find the best solution among the alternative re-scheduling solutions in the “EOT GUI+”. The benchmark framework has the following motivated attributes to be considered:

- Total final delay (TFD5+)
- Total final delay (TFD1+)
- Maximum delay of a single train
- Average Final delay (AFD)
- Total accumulated delay (TAD)
- Total Number of delayed trains
- Number of delayed trains (NTFD5+)
- Number of delayed trains (NTFD1+)
- Total delay cost (TDC)
- Robustness

Observations from the initial pre-calculations of the attribute values indicated that for some scenario the attribute values are conflicting which makes it hard to find a re-scheduling solution dominating the other solutions in all aspects. Consequently, we have to narrow down the set of attributes used for deciding which solution is the best and rank these attributes internally. Note that, other attributes are still valid to compute and present, but not to suggest the most relevant solution. So, we are considering the following attributes:

- Average final delay includes the TFD5+ and TFD1+.
- Maximum delay of a single train is chosen because it is one of the most referred attribute.
- Total number of delayed trains includes the NTFD5+ and NTFD1+.
- Robustness includes the buffer time of the re-scheduling timetable which helps to avoid the further delays i.e. makes the timetable as robust.

Total delay cost mainly depends on the total final delay hence it is considered as one of the least important attribute. Total accumulated delay is one of the least referred attribute from the literature when compare to other motivated attributes. So it is considered as least important attribute. Most
important attribute values are plotted in bar chart to prioritize among them. Bar chart (Fig 19, 20 and 21) compares the various alternative solutions.

6.1.3 Scenarios behind the instances
Description of how the scenarios behind the instances look are given here. Figure 9 represents the Railway network of the stretch Mjölby-Katrinholm which is used for the scenarios and corresponding experiments. Railway network is divided into sections; the section can be line section or station section. Three different types of disturbances are chosen [37], which are as follows:

Type 1: A train which suffers from a temporary delay at one section within the traffic network, long-distance trains run within the traffic network frequently suffer from this delay.

Type 2: A train which suffers from a permanent delay fails to function improperly results in increased running times on all line sections, frequently trains are affected by this problem.

Type 3: A train which suffers from an infrastructure failure i.e. speed reduction on a certain section, results in increased running times for all trains in that same section. This disturbance type is not frequent but a serious problem which has a high impact within that traffic network.

There are different scenarios which fall under above types of disturbances; we choose re-scheduling solutions containing one scenario for each disturbance type. Scenarios used in the re-scheduling solutions are scenario 5, scenario 14 and scenario 20 as in “Design of an effective algorithm for fast response to the re-scheduling of railway traffic during disturbances” [37]. Figure 18 illustrates the Timetable for the traffic scenarios 5, scenario 14 and scenario 20 respectively, which are described as follows:

Scenario for disturbance type 1: Passenger train 80866 is heading towards the north starting from Linköping (Lp) as illustrated in Figure 18, the train path from Linköping (Lp)-Linghem (Lgm) is a double-tracked section. Linköping is the important connection point in the Railway network (illustrated in Figure 9). This train 80866 is delayed 12 minutes across the train path Linköping – Linghem.

Scenario for disturbance type 2: Passenger train 8764 is heading towards the north starting from Mjölby (My) as illustrated in Figure 18, the train path from Mjölby (My)-Mantrop (Mt) is a double-tracked section. This train 8764 has a permanent malfunction results in 50% increased run times on line sections starting at Mjölby-Mantrop.

Scenario for disturbance type 3: All trains between Linköping (Lp)-Linghem (Lm) has Speed reduction (all trains get a running time of 15min) starting train 538. The train path from Linköping (Lp)-Linghem (Lgm) is a double-tracked section. Linköping is the important connection point in the Railway network (illustrated in Figure 9).

Above scenarios present in the re-scheduling solutions are chosen here for experiment.
6.1.4 Computation of attribute values

The formulas from the chapter 4 and 5 are used to compute the attribute values. An example re-scheduling solution from the sample data instances are taken to show how the attribute values are computed in the “EOT GUI+”. A single re-scheduling solution representing the scenario 5 is taken here to compute the attribute values. Total final delay, Total number of delayed trains, Average final delay, Total delay cost and Robustness attributes computation are as follows:

6.1.4.1 Total Final Delay

Total final delay (TFD) = \( \sum_{i=1}^{n} \left\{ \sum_{k=1}^{m_i} \left( \max \left[ 0, \left( NAT \right)_k \text{ at final destination} \right) - \left( IAT \right)_k \text{ at final destination} \right) \right\} \)

\( TFD = 13.6 \) minutes

The suffix variable \( i \) is used as an index for train \( i \) in the set of \( n \) number of trains, i.e. \( i \in \{1…n\} \) and \( k \) is used as an index for event \( k \) in the set of \( m_i \) events of train \( i \), i.e. \( k \in \{1…m_i\} \).
6.1.4.2 Total Number of Delayed Trains

Total number of delayed trains = \((NTFD5^+) + (NTFD1^+)\)
Total number of delayed trains = 1 + 1
Total number of delayed trains = 2

6.1.4.3 Average Final Delay

Average final delay (AFD) = \(\frac{((TFD5^+) + (TFD1^+))}{TND}\)
AFD = \(\frac{((13.6) + (1.65))}{2}\)
AFD = 7.625 minutes

6.1.4.4 Total Delay Cost

Total delay cost (TDC) = \(\sum_{i=1}^{n} \max \{0, ((TFD)_{at final destination} \ast (Delay cost)_{i})\}\)
TDC = ((13.6) \ast (194)) + ((1.65) \ast (194))
TDC = 2958.5SEK

Delay cost is taken from the Table 4. The suffix variable \(i\) is used as an index for train \(i\) in the set of \(n\) number of trains, i.e. \(i \in \{1 \ldots n\}\).

6.1.4.5 Robustness

Buffer time (B) for New timetable = \(\sum_{i=1}^{n} \sum_{k=1}^{m_{i}} \max \{0, (Nat)_{k} - (NDT)_{k} - ([minimum run time)_{k}]\}\)
B = 101.85 minutes
Hence, Robustness(R) = 101.85 minutes

The suffix variable \(i\) is used as an index for train \(i\) in the set of \(n\) number of trains, i.e. \(i \in \{1 \ldots n\}\) and \(k\) is used as an index for event \(k\) in the set of \(m_{i}\) events of train \(i\), i.e. \(k \in \{1 \ldots m_{i}\}\).

6.1.5 Experimenting the “EOT GUI+” with alternative re-scheduling solutions

The “EOT GUI+” is experimented with alternative re-scheduling solutions. The alternative re-scheduling solutions are loaded in the “EOT GUI+”, then the benchmarked solutions are analyzed and the bar charts are drawn for those to prioritize the attributes. Table 5 indicates the scale for drawing bar charts Figure 19, 20 and 21. Since the values obtained from the solution are too small and also too large for some attributes, the visibility of the graph is increased by choosing scale for the attributes.

<table>
<thead>
<tr>
<th>Scale for drawing bar chart</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average final delay (AFD)</td>
<td>1 minute</td>
</tr>
<tr>
<td>Max delay of a single train</td>
<td>1 minute</td>
</tr>
<tr>
<td>Total number of delayed trains</td>
<td>1 train</td>
</tr>
<tr>
<td>Robustness</td>
<td>10 minutes</td>
</tr>
</tbody>
</table>

The two re-scheduling solutions considered for Scenario 5 are taken for benchmarking. The attributes used in the bar chart are listed in the Table 6 and the values used in the table are calculated from the re-scheduling solutions.
The above bar chart displays the attribute values and it infers how they differ from solution 1 and solution 2. The combination of Average final delay, Maximum delay of a single train, Total number of delayed trains and Robustness attributes will help us to select the best re-scheduling solution. The attribute value of Average final delay, Maximum delay of a single train and Total number of delayed trains in solution 1 is same as solution 2. In Table 6, total accumulated delay shows a difference among two re-scheduling solutions, because it is calculated for the train after each delay event that occurs during its journey. Hence this attribute is not considered for comparison here. Encircled value in Table 6 indicates the robustness value, which is larger than in the other solution and it also visible from the bar chart. Hence the Robustness attribute helps us to select the best re-scheduling solution among these two alternatives.

The two re-scheduling solutions considered for Scenario 14 are taken for benchmarking. The attributes used in the chart are listed in the Table 7 and the values used in the table are calculated from the re-scheduling solutions.
The above bar chart displays the attribute values and it infers how they differ from solution 1 and solution 2. The combination of Average final delay, Maximum delay of a single train, Total number of delayed trains and Robustness attributes will help us to select the best re-scheduling solution. The attribute value of Maximum delay of a single train and Total number of delayed trains in solution 1 is same as solution 2. In Table 7, even though total accumulated delay shows a difference among two re-scheduling solutions, this attribute is not considered for comparison here. Encircled value in Table 7 indicates the Average final delay value which is less than in the other solution and the Robustness value which is larger than in the other solution. It is also visible from the bar chart, that Average final delay and Robustness attributes help us to select the best re-scheduling solution among these two alternatives.
Similarly the alternative re-scheduling solutions considered for Scenario 20 are taken for benchmarking. The attributes used in the chart are listed in the Table 8 and the values used in the table are calculated from the re-scheduling solutions. In this table the field name S1 to S7 refers to the attribute values for solution 1 to solution 7.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S5</th>
<th>S6</th>
<th>S7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total final delay (TFD5+) in minutes</td>
<td>385.483</td>
<td>385.5</td>
<td>310.567</td>
<td>344.733</td>
<td>345.433</td>
<td>355.283</td>
<td>355.983</td>
</tr>
<tr>
<td>Total final delay (TFD1+) in minutes</td>
<td>7.633</td>
<td>0.0</td>
<td>5.617</td>
<td>9.383</td>
<td>9.383</td>
<td>9.383</td>
<td>9.383</td>
</tr>
<tr>
<td>Max delay of a single train in minutes</td>
<td>51.5</td>
<td>50.417</td>
<td>48.15</td>
<td>51.5</td>
<td>51.5</td>
<td>51.5</td>
<td>51.5</td>
</tr>
<tr>
<td>Average final delay (AFD) in minutes</td>
<td>21.84</td>
<td>25.7</td>
<td>18.599</td>
<td>19.673</td>
<td>19.712</td>
<td>20.259</td>
<td>20.298</td>
</tr>
<tr>
<td>Total accumulated delay (TAD) in minutes</td>
<td>3814.117</td>
<td>4345.133</td>
<td>3920.15</td>
<td>3699.083</td>
<td>3700.483</td>
<td>3759.833</td>
<td>3761.233</td>
</tr>
<tr>
<td>Total number of delayed trains</td>
<td>18</td>
<td>15</td>
<td>17</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>No. of delayed trains (NTFD5+)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>14</td>
</tr>
<tr>
<td>No. of delayed trains (NTFD1+)</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total delay cost in SEK</td>
<td>62465.553</td>
<td>68387.056</td>
<td>55750.694</td>
<td>60622.553</td>
<td>60758.353</td>
<td>62669.253</td>
<td>62805.053</td>
</tr>
<tr>
<td>Robustness in minutes</td>
<td>333.983</td>
<td>326.467</td>
<td>226.217</td>
<td>291.8</td>
<td>292.5</td>
<td>302.35</td>
<td>303.05</td>
</tr>
</tbody>
</table>

Table 8. Attribute table-Scenario 20.

The above bar chart displays the attribute values and it infers how they differ from solution 1 to solution 7. The combination of Average final delay, Maximum delay of a single train, Total number of delayed trains and Robustness attributes will help us to select the best re-scheduling solution. Since there are more possible solutions to be compared with one another, there may be conflicts between the attributes to choose the best re-scheduling solution during pair-wise comparison. The conflicts are discussed in forthcoming paragraphs.
To handle the type of conflicts mentioned previously, the attributes need to be prioritized. By experimenting with alternative re-scheduling solutions, analyzing the bar charts and also the results of the literature review and the main objectives of Trafikverket [6, 40] suggest a way of prioritization. The order of prioritized attributes is as follows:

- Average final delay,
- Maximum delay of a single train,
- Total number of delayed trains and
- Robustness.

Average final delay has first priority because it includes total final delay, i.e. the delay factor and also the total final delay is the most referred attribute from the literature. Maximum delay of a single train has second priority because it is most referred attribute from the literature. Total number of delayed trains has third priority because it is next most referred attribute from the literature and finally robustness because if the re-scheduling solution is more robust then it is less optimal [34]. Hence robustness is considered last among the prioritized attributes.

After analyzing alternative re-scheduling solutions, a solution is selected among them with the help of attributes. The order of considering the attributes to select a solution may vary from one traffic dispatcher to another dispatcher with respective to the railway network.

The solution S2 and solution S3 from Table 8 are considered here for discussing conflicts between the attributes. In this table, even though total accumulated delay shows a difference among two re-scheduling solutions, this attribute is not considered for comparison in our thesis. Encircled value indicates the Average final delay and Maximum delay of a single train values for the solution S3 are less than the solution S2, but the Total number of delayed trains is less in solution S2 than the solution S3. Thus Average final delay and Maximum delay of a single train has higher priority than other attributes, the solution S3 is selected as a best solution than solution S2. Since there will be best and worst case of the attribute values in the alternatives solutions, those cases of scenario 20 are discussed below.

Best Case: In best case the dispatchers have the same prioritization as we have assumed and then the solution S3 is selected as the best re-scheduling solution among the alternative solutions S1, S2, S4, S5, S6 and S7. The reason for choosing S3 as best re-scheduling solution is based on two attributes (Maximum delay of a single train and Average final delay). Maximum delay of a single train and Average final delay are the attributes among the final selected attributes chosen for comparing alternative solutions.

Worst Case: Consider there is another alternative solution S8, which has an Average final delay of 18.57 minutes and a Maximum delay of a single train of 56.8 minutes. Then this solution will be selected as the best re-scheduling solution among the alternatives by our “EOT GUI+”. But in general the best solution should be Solution S3 because it has better Maximum delay of a single train when compared to Solution S8 which has an insignificantly better value for Average final delay. So, if a situation like this would occur, it could not be handled by our “EOT GUI+”.

Finally we conclude that through this experiment, the attributes are finalized to select the best solution among the alternatives are Average final delay, Maximum delay of a single train and Total number of delayed trains and Robustness.

### 6.2 Visualization of Solutions

### 6.2.1 Existing Options

The existing options in the “EOT GUI” are as follows:
• Visualization of a solution at single window
• Train paths in plotted graph are in different color for the different solutions
• The summary window is appended with existing frame window
• Initial timetable and Re-scheduling timetable is viewed at the same time-distance graph.

6.2.2 Enhanced Options
We have made enhanced options for the “EOT GUI” and improved it with possible changes to compare pair wise solutions. This improvement is made because EOT researcher needs a GUI to execute their algorithm for visualizing pair-wise comparison of alternative re-scheduling solutions.

The “EOT GUI+” is designed for the train dispatchers’ decision support system while re-scheduling the alternative solutions. By using this “EOT GUI+”,

• Train dispatcher can be able to visualizing two re-scheduling solutions simultaneously. So, the comparison between the solutions is made easy.
• File name visibility of the solution.
• Train number button is popped up when mouse over event occurs in the train paths.
• Summary window is separately popped up for the train dispatchers.
• The alternative re-scheduling solutions are benchmarked and the attribute values are compared in a table.
• Finally the best re-scheduling solution is selected which is useful for the train dispatchers.

The snapshots of the “EOT GUI+” with the descriptions are discussed in the following sections.

6.2.2.1 Split window option
The Figure 22 depicts the option of split window. The new file menu ‘Option’ has menu item as ‘Split Window’ which takes the single window to split window. This new file menu and menu item is appended with existing menu bar options. After selecting this menu item, it is replaced by ‘Single Window’ option.

![Figure 22. A snapshot of the split window option.](image)
6.2.2.2 Split window
The Figure 23 depicts the split window. Split window has pair wise frame in which each frame displays independently. In each window we can run different solution so that the comparison between each solution is made easier and comfortable.

![Figure 23. A snapshot of the split window.](image)

6.2.2.3 Single window option
The Figure 24 depicts the option of single window. The new file menu ‘Option’ has menu item as ‘Single Window’ which takes the split window to single window. This new file menu and menu item is appended with existing menu bar options. After selecting this menu item, it is replaced by ‘Split Window’ option.

![Figure 24. A snapshot of the single window.](image)

6.2.2.4 File name visibility of the solution
The Figure 25 depicts file name visibility of the current solution. The current loaded solutions S2 and S3 are the instances of Scenario 20. Once after selecting the given solution, the file name of the corresponding solution will be visible in the menu bar. The file name will be differentiated by default selection within quotes. The dark lines in the snapshot indicate the trains which are delayed more than 5 minutes from the scheduled timetable and the dotted lines indicate the trains which are re-scheduled from the scheduled timetable. To identify the file names in the below figure, they are encircled with red color.
6.2.2.5 Train number button popped up when mouse over event occurs

The Figure 26 depicts train number button popped up in the selected event. The train number button arises once any particular event is selected. This selection can be mouse clicked or mouse over event. This option is included for the flexibility of selecting the event. The action of train number button gives the selected event information which has train number, event number, train operator name, block name, start time, stop time, deviation, minimum travel time and track number. To identify in the below figure, the train number buttons are encircled with red color.
6.2.2.6 Summary window separation
The Figure 27 depicts the summary window. Initially summary was appended to the existing frame window. Now it is removed from the frame window and displayed as separate summary dialog box. This summary shows the values of

- Total final delay
- Total final delay (TFD5+)
- Total train delay (TFD1+)
- Maximum delay of a single train
- Average delay (AVD)
- Total accumulated delay (TAD)
- Total Number of delayed trains
- Number of delayed trains (NTFD5+)
- Number of delayed trains (NTFD1+)
- Total delay cost (TDC)
- Robustness

Figure 27. A snapshot of the summary window.

6.2.2.7 Benchmarked solutions window
The Figure 28 depicts the benchmaked solutions window. This window shows the table which has attributes and its values of two re-scheduling solutions for better comparison. The benchmaked solutions window has the following attributes:

- Total final delay (TFD5+)
- Total final delay (TFD1+)
- Maximum delay of a single train
- Average Final delay (AFD)
- Total accumulated delay (TAD)
- Total Number of delayed trains
- Number of delayed trains (NTFD5+)
• Number of delayed trains (NTFD1+)
• Total delay cost (TDC)
• Robustness

Finally the best re-scheduling solution is selected which is based on the following attributes: Average final delay, Maximum delay of a single train, Total number of delayed trains and Robustness.

Figure 28. A snapshot of the benchmarked solutions window.
7 DISCUSSION

The main objective of our thesis is to find the relevant attributes to compare the re-scheduling solutions and also to enhance the visual tool which is already developed. Before getting into the attribute search, the train dispatcher problems are studied. The train dispatcher real-time problems are found from the STEG research papers and also the current train traffic infrastructure is studied. The related research of our thesis is studied, to find the relevant attributes.

An analysis is made on the relevant attributes to present the importance of every single attribute. After analysis, motivations of selected attributes are addressed. Formulas to compute the attribute values are found from the literature; the formulas are modified or newly created based on the need. Further motivations are made when comes to real-time implementation.

“EOT GUI+” is visualizing the comparison and benchmark of two re-scheduling solutions. “EOT GUI+” computes the attribute values from the re-scheduling solutions. The formulas defined are now used in the implementation. The instances of two re-scheduling solutions are loaded in “EOT GUI+”, to compute the attribute values. There are efficient formulas to calculate the attribute values but with the available data we found alternative formulas. An experiment is conducted to select the attributes for choosing the best solution. Outcome of these experiments is the benchmarked re-scheduling solutions, which has final selected attributes to select the best solution among the alternative re-scheduling solutions to the user of the “EOT GUI+”.

7.1 Validity Threats

Validity threats are the process of checking the validity of the experiments [43]. The types of validity threats are follows.

- Internal validity
- External validity
- Construct validity
- Conclusion validity

7.1.1 Internal validity

Internal validity threats are influences which affect the independent variable without the knowledge of researcher [43]. The threat is based on a previous experiment subjects are classified into experimental groups. During experiment to avoid conflicts between the attributes, prioritization is made based on the publications and Trafikverket [6, 40]. This prioritization may not be as relevant or valid when experiments with other data instances are done.

7.1.2 External validity

External validity threats are the conditions which limit our ability to generalize our experiment results to industrial practice [43]. The threat is the wrong people participate in the experiment. Here, the EOT researchers as well as programmers can participate in the experiment.

7.1.3 Construct validity

Construct validity is generalizing the result of the experiment to the concept behind it [43]. A single type of observations is a threat that if this observation gives a measurement bias, then the experiment misleads. To overcome such type of issue we have done experiments with more than a single disturbance problem.

7.1.4 Conclusion validity

Conclusion validity is the issue affects the ability to draw the correct conclusion about the outcome of an experiment [43]. There is a threat that the implementation will not be similar between different
persons during experiment. So, the “EOT GUI+” is enhanced as much as possible according to the need of the EOT researchers and traffic dispatchers.

7.2 Limitations and Future Work

In our thesis the EOT and STEG project reports are analyzed to gather information about the train dispatcher problems. But in future, Swedish train dispatchers can be interviewed for gathering information about the real-time problems which they are facing while re-scheduling the alternative solutions.

In our thesis, benchmarking framework is set for comparing two re-scheduling solutions. Benchmarking framework has following implications; the provided data instances for experiment have three types of disturbances. The instances of alternative re-scheduling solutions are benchmarked for selection of attributes. To avoid data conflicts prioritization is made between the attributes after the experiment. In future prioritization between the attributes may differ based on the type of disturbances. During the experiment, we have used a set of different problem instances (2+2+7) representing three different types of disturbances. Data requirements may be an issue for our thesis, the access to the required data is not guaranteed for reliability. In future the performance of “EOT GUI+” can be improved by experimenting with a larger number of instances. The re-scheduling solution contains the planned traffic for the next 90 minutes, but delay events may happen outside of the planned horizon time. That is, some trains may continue outside of this planned time horizon and geographical span.

In the “EOT GUI+”, two re-scheduling solutions are visualized simultaneously. But the time-distance graph of the re-scheduling solutions does not indicate the delay location and also does not indicate whether one train is delayed more or less in the alternative solution. Delay location can be indicated in further development of the “EOT GUI+”. Visualization of more than two re-scheduling solutions simultaneously can be implemented further; this implementation is required when there are more relevant alternative solutions for a single train traffic problem.

From the “EOT GUI+”, the benchmarked re-scheduling solutions are used for the train dispatchers to select the best solution among the alternative re-scheduling solutions. However, the experimental evaluation and analysis has shown that the “EOT GUI+” would not fit directly to the needs of the train dispatchers and our work should be seen as a starting point for the researchers whom are working with the development of decision support systems in this context.
8 CONCLUSION
This chapter describes the answers to our research questions.

The answer to research question 1 is “Based on the experimental results and the analysis of what the research community and the main stakeholder (i.e. Trafikverket) consider are the most important attributes in this context, the final set of attributes to use includes average final delay, maximum delay of a single train, total number of delayed trains and robustness”.

The answer to research question 2 is “The attribute values are computed by using the formulas either found in the literature and possibly modified, or defined within this thesis project. These formulas are first experimentally evaluated and then finalized to be used when calculating the attribute values in the EOT GUI+”.

The answer to research question 3 is “The pair-wise comparison of the alternative re-scheduling solutions is visualized by the EOT GUI+”.

The answer to research question 4 is “In order to assess the use of the attributes for benchmark solutions, experiments were conducted using the EOT GUI+ and a set of sample solutions for three different disturbance scenarios provided by the EOT project. The EOT GUI+ only performs a benchmark of two solutions at a time (i.e. a pair wise benchmark) and computes the attribute values for the chosen attributes”.

REFERENCES


