Investigation on the usability of detections coming from the bus monitoring system in Delft

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To Prof. Van Zuylen
To Prof. Van Zuylen

Sincerely,

[Signature]
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Introduction

A network of bus monitoring detectors has been recently set up in Delft, The Netherlands. This system is the result of an experiment: realizing the bus monitoring by means of bus selective detectors which are already used in Delft for the bus priority system.

The research scope and results

At the beginning of this research the bus monitoring system only stored detections in a database, but no software for the analysis of detections had been developed. Realizing a software package as well as an investigation on the usability of this kind of detections came out as our task. Despite the monitoring system limits (described in chapter 1 and 2), on the basis of some months detections, interesting results have been found for the detection usability. Thanks to the help of an expert programmer, a complex software package has been implemented for realizing an automatic detection processing.

As a first step of the research a program has been implemented for the acknowledgement and selection of only reliable detections of the database, see chapter 3. Some other programs have been developed in order to use detections with the following scopes:
- the assessment whether a trip was executed;
- the acknowledgement whether a trip is usable for trip time analysis;
- the trip time analysis
- the control of detector operation.

Refer to chapters 4 and 5 for more details and for an application of the whole software package to line 64.

Parties interested in the research results

Given the good usability of detections of this new monitoring system, given also the high quality of the implemented software package, parties interested in the research results are:

- The DELFT MUNICIPALITY, which subsidizes the public transport companies for an agreed service. The control of the actual service, and the comparison with the agreed service can be executed by the implemented software now. The Municipality is also interested in this research because it is the owner of the detectors. A procedure for the assessment of the detector performance has also been realized.

- The local TRANSPORT COMPANIES, CONNEXXION and HTM. The analysis of detections has showed some interesting features of the service operation but also some mistakes in the timetable, see the case of line 64 in chapter 5. The possibility to find mistakes in the timetable is very important for the public transport companies. In these cases the companies could ask for a revision of (eventual) penalties applied for not respecting the planned service. As a consequence an agreement should be found on a new timetable. TRITAPT software, which has been chosen for the trip time analysis, provides important graphs and suggestions for designing better timetables.

- CITIZENS are indirectly involved. They can enjoy the common efforts of Municipality and Public Transport Companies for improving the service design and execution.

- OTHER MUNICIPALITIES could be interested. In fact the kind of detectors used in Delft is also available in many cities in the Netherlands. Like in Delft, those detectors are used for the bus priority system as devices which detect and identify buses when getting close to intersections. Like in Delft, the same detectors could be used also as parts of bus monitoring systems.
1 The bus monitoring network in Delft

This chapter introduces some important features of the bus monitoring system set up in Delft. Subjects of the three following sections are:
- the main facilities which are used for the individual bus monitoring,
- the reasons for an experimental bus monitoring system,
- the observability of buses along the lines in Delft.

1.1 Individual bus monitoring

The following section provides a description of the main facilities of the bus monitoring system set up in Delft:
- VETAG detectors for the detection and identification of busses in the traffic
- VETAG detector connections to a control computer for the collection of bus observations.

VETAG detectors

Like in the most of the Netherlands, in the city of Delft the detection and identification of busses in the traffic stream is made by a network of VETAG detectors. The VETAG (VEhicle TAGging) system uses components in the vehicle as well as in the road, see figure 1.1.

The road side part consists of copper windings buried in the pavement, here referred to as loops. High frequency current goes through the loop 40 times each second as a carrier for an interrogator message to busses. While not interrogating the loop remains listening to eventual bus replies. A decoder for vehicle reply is therefore provided.

The vehicle side part consists of an antenna to receive the interrogator signal and to reply by the emission of the transponder signal. This vehicle identity signal is standardized within the Netherlands and contains also information about:
- Service type
- Bus line number
- Driver code.

![Figure 1.1 - VETAG detector for the acknowledgement of a bus in the traffic stream.](image)

VETAG detectors are just a part of the Delft bus monitoring facilities. They come from the existing bus priority system, where they are only used to identify busses in the traffic stream, therefore this ‘precious information’ remains locally and is only momentarily available. A bus monitoring system requires instead a central and permanent record of detections. Some more facilities had to be added to VETAG detectors to realize this scope. The adopted solution is now described.
VETAG detector connection to a remote computer and the Detection database

Every VETAG detector for the bus monitoring system in Delft uses a modem and phone cable connection to a computer at the Traffic Research Section of the Municipality, see figure 1.2. Every time a bus passes over a detector, its transponder message is decoded and real-time sent to the central computer. Over there two steps are made:

- The bus detection is amended with the date and time (time-stamping process).
- The time-stamped detection is stored in a database (Detection database).

The Detection database can also be accessed by another computer which is located at the Transportation Research Laboratory of Delft University of Technology. By means of this link two goals can be achieved:

- Our laboratory can remotely update its own copy of the Detection database.
- The clock of the time-stamping machine at the Municipality can be kept synchronized with the rest of the world.

![Figure 1.2 - VETAG detectors working for the bus monitoring system.](image)

Data contained in a Detections database day-file look like a sequence of time stamped detections coming from all detectors in a day. See table 1.1. Every row is an individual detection and its meaning (looking at the first one for instance) is the following: in the day 30 January 1999 at 7:49:20, the VETAG loop number 0 of the intersection 2 has detected a tram in service on line 1. The tram driver is executing a sequence of trips defined as in the trip shift 8.

Let’s get familiar with this table. In a 6 minute interval, 24 detections have been produced. They involve:

- 6 bus lines: (1, 48, 61, 62, 64, 65);
- 9 bus drivers: (0, 1, 4, 5, 6, 8, 28, 30, 39);
- 12 different intersections: (2, 6, 10, 11, 17, 21, 22, 30, 60, 77, 79, 99);
- 23 different loops: (2, 6, 10, 11, 17, 21, 22, 30, 60, 77, 79, 99) (Group loop, loop, loop, ...)

1 It is important to realize that for brevity’s sake only buses have been mentioned, but actually also trams are visible in the Detection Database.
2 Given that everyday a driver is assigned with a shift number, this number can be used as a daily driver identity code. For this reason the extreme right column showing the trip shift number is here referred to as “Driver”.

---

1 It is important to realize that for brevity’s sake only buses have been mentioned, but actually also trams are visible in the Detection Database.
2 Given that everyday a driver is assigned with a shift number, this number can be used as a daily driver identity code. For this reason the extreme right column showing the trip shift number is here referred to as “Driver”.

---

4
Table 1.1 - Data format of an Observation database day file.

1.2 Origin of the bus monitoring system in Delft

Two important features of the Delft bus monitoring system are: Vetag detectors are used for the bus identification; all detectors are located nearby controlled intersection. The reasons for these choices are illustrated in this section, while some important consequences are the subject of section 1.3.

The choice of VETAG detectors

As explained the Municipality of Delft has chosen to realize the bus detection and identification by means of Vetag loops, on the roads, and Vetag compatible transponders on board of public transport vehicles. This choice was not casual, in fact the existing system for bus priority at controlled intersections already provided:

- several groups of Vetag detectors for the bus identification in the traffic;
- Vetag compatible transponders on board of all the busses and trams of the local companies.

Therefore some Vetag detectors used for the priority system have been made working also for the bus monitoring, while some further Vetag detectors have been set up with the only scope of the bus monitoring. A look at figure 1.3 shows that all Vetag detectors are located nearby controlled intersections. On the contrary the new detectors could have been located at bus stops. This way they could have recorded the passing time at stops and the time spent for boarding and alighting passengers. An explanation for such a location of detectors is given in the next section.

In figure 1.3 red rings with a number inside are used for the controlled intersections. Blue circles indicated that the intersection is equipped with groups of Vetag detectors.

---

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Detector</th>
<th>Group</th>
<th>Loop</th>
<th>Service</th>
<th>Line</th>
<th>Driver</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999Jan30</td>
<td>7:49.20</td>
<td>2 U</td>
<td>lus 0</td>
<td></td>
<td>stadstram 00</td>
<td>lijn 1</td>
<td>vtg 8</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:49.20</td>
<td>2 U</td>
<td>lus 0</td>
<td></td>
<td>stadstram 00</td>
<td>lijn 1</td>
<td>vtg 8</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:49.31</td>
<td>22 U</td>
<td>lus 1</td>
<td></td>
<td>stadstram 00</td>
<td>lijn 1</td>
<td>vtg 4</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:49.51</td>
<td>2 U</td>
<td>lus 1</td>
<td></td>
<td>stadstram 00</td>
<td>lijn 1</td>
<td>vtg 8</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:50.07</td>
<td>22 U</td>
<td>lus 2</td>
<td></td>
<td>stadstram 00</td>
<td>lijn 1</td>
<td>vtg 4</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:50.15</td>
<td>10 U</td>
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<td></td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vtg 28</td>
</tr>
<tr>
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<td>7:50.34</td>
<td>10 U</td>
<td>lus 2</td>
<td></td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vtg 28</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:50.38</td>
<td>30 U</td>
<td>lus 2</td>
<td></td>
<td>stadstram 00</td>
<td>lijn 1</td>
<td>vtg 8</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:50.49</td>
<td>11 U</td>
<td>lus 1</td>
<td></td>
<td>streekdienst</td>
<td>lijn 65</td>
<td>vtg 30</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:50.50</td>
<td>30 U</td>
<td>lus 1</td>
<td></td>
<td>stadstram 00</td>
<td>lijn 1</td>
<td>vtg 8</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:51.07</td>
<td>21 U</td>
<td>lus 2</td>
<td></td>
<td>streekdienst</td>
<td>lijn 62</td>
<td>vtg 6</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:51.15</td>
<td>60 U</td>
<td>lus 1</td>
<td></td>
<td>streekdienst</td>
<td>lijn 61</td>
<td>vtg 8</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:51.18</td>
<td>79 U</td>
<td>lus 2</td>
<td></td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vtg 1</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:51.19</td>
<td>11 U</td>
<td>lus 2</td>
<td></td>
<td>streekdienst</td>
<td>lijn 1</td>
<td>vtg 39</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:51.27</td>
<td>21 U</td>
<td>lus 1</td>
<td></td>
<td>streekdienst</td>
<td>lijn 62</td>
<td>vtg 6</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:52.06</td>
<td>77 U</td>
<td>lus 1</td>
<td></td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vtg 0</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:53.09</td>
<td>99 U</td>
<td>lus 8</td>
<td></td>
<td>streekdienst</td>
<td>lijn 62</td>
<td>vtg 6</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:53.38</td>
<td>30 U</td>
<td>lus 6</td>
<td></td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vtg 0</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:53.57</td>
<td>17 U</td>
<td>lus 1</td>
<td></td>
<td>stadstram 00</td>
<td>lijn 1</td>
<td>vtg 4</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:54.28</td>
<td>30 U</td>
<td>lus 7</td>
<td></td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vtg 0</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:54.31</td>
<td>6 U</td>
<td>lus 3</td>
<td></td>
<td>streekdienst</td>
<td>lijn 65</td>
<td>vtg 30</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:54.39</td>
<td>21 U</td>
<td>lus 4</td>
<td></td>
<td>streekdienst</td>
<td>lijn 61</td>
<td>vtg 5</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:54.58</td>
<td>22 U</td>
<td>lus 4</td>
<td></td>
<td>streekdienst</td>
<td>lijn 48</td>
<td>vtg 8</td>
</tr>
<tr>
<td>1999Jan30</td>
<td>7:55.16</td>
<td>21 U</td>
<td>lus 3</td>
<td></td>
<td>streekdienst</td>
<td>lijn 61</td>
<td>vtg 5</td>
</tr>
</tbody>
</table>
Location of bus monitoring detectors

Before realizing the bus monitoring system, an important project was already set up in Delft. At every controlled intersection several non selective detectors are used to detect (but not identify) every kind of vehicle driving nearby the intersection. The scope of this monitoring is to feed a traffic-lights control program run by a local computer. The project includes also a modem and phone cable connection to a computer located at the Municipality. By means of this connection the status of non selective detectors can be remotely seen. This project provided the bus monitoring system with the following facilities:
- several points on the roads where to locate Vetag detectors without needing to set up new phone connections,
- the central computer for the storage of bus detections,

Figure 1.4 shows one of the controlled intersections (number 10) where VETAG loops use the available phone cable connection to the Municipality. For the observer’s convenience only VETAG loops are displayed (diamond boxes), but it is to remark that lots of non selective detectors are also located at this intersection.
1.3 The observability of buses along the lines

Limits of the bus monitoring system in Delft

Some economic advantages have come from the design of a bus monitoring system which used so many available facilities. Some limits to the bus observability came from that choice and brought consequences in the usability of detections for the analysis of public transport performance. Three limits are:

- **content limited observability of buses.** As seen VETAG detectors receive from the bus only a message showing the vehicle identity. No information is available about the time the bus spends running or keeping stationary at bus stops or at other points of the line. This information may be available in systems which use vehicle on board computers for the bus monitoring.

- **discontinuous observation of the trip execution.** A trip can only be described as a sequence of passing times at detectors along the line. No information is available about what happened between detectors.

- observation points are not located at bus stops but nearby some controlled intersections in the city. Implications follow:

  - no information is available for the arrival and leaving time at bus stops,
  - the bus observability along a line depends on the availability of controlled intersections along it. Lines not following the most important streets in fact are less likely to cross controlled intersections, therefore detectors.

The case of lines within the city’s boundaries

Since all detectors are within the city of Delft, we restrict the bus observability analysis to those lines which remain within the city’s boundaries, namely: line 60, 61, 62, 63, 64. See figure 1.5.

At the beginning of the research, bus lines 60, 61, 62 and 63 showed very few intersections with bus monitoring detectors respect to the number of bus stops. Furthermore, half of the available detectors were concentrated nearby the Station Centrum terminal (Group 99). Line 64 instead showed a more frequent and widespread trip observability, really much better than all the other lines. Therefore Line 64 was chosen for showing how the developed software allows an analysis of the public transport performance. See chapters 4 and 5.

It must be said that at the end of this thesis work the number of intersections equipped for the bus monitoring has increased, therefore a more significant analysis of the service performance can be realized also for other lines, such as: number 1 (tram), 60 and 62 (bus).

Figure 1.6 at page 7 instead illustrates on a map the location of intersections for the bus monitoring and the bus lines within Delft.

<table>
<thead>
<tr>
<th>Bus lines</th>
<th>Int.</th>
<th>70</th>
<th>69</th>
<th>17</th>
<th>21,22</th>
<th>99</th>
<th>02</th>
<th>41</th>
<th>63</th>
<th>30</th>
<th>60</th>
<th>62</th>
</tr>
</thead>
<tbody>
<tr>
<td>60-62 Sportpark</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>61 Kuyperwijk</td>
<td>14</td>
<td>21,22</td>
<td>99</td>
<td>22</td>
<td>22,21</td>
<td></td>
<td>60</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>63 Station Centrum</td>
<td>99</td>
<td>22</td>
<td>8,11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>64 Abtwoudsepark</td>
<td>79</td>
<td>77</td>
<td>30</td>
<td>02</td>
<td>99</td>
<td>22</td>
<td>06</td>
<td>10</td>
<td>60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Abtwoudsepark</td>
<td>85</td>
<td>53</td>
<td>30</td>
<td>02</td>
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<td>21</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1.5 - Distribution of bus stops and intersections (equipped for the bus monitoring) along the lines. At the end of this research (July 1999) the bus observability had improved in lines 60, 62 and 1. (E.g. Look at line 60 between intersections 02 and 30. Two intersections 41 and 53 have been added). Intersections 13, 45, and 74 are possible suggestions aimed to reduce the number of bus stops between detectors and to detect buses at the terminal of lines 63 and 62.
2 Origin, scope and first steps of the research

2.1 Origin and scope of the research

As explained in the first chapter, the bus monitoring system set up in Delft is the result of an experiment. The network has been «quickly» obtained by using some already existing facilities. Consequences have come from that choice for the kind of bus observability along the lines and an important question had to be answered: what is the usability of these detections? Among several possible uses for detections, our investigation focused on the following topics:
- usability of detections for the trip time analysis
- analysis of presence/absence of detections for a scheduled trip

2.2 The first step of the research

A matter with available detections

A first look at the Detection database has revealed an important aspect of this data collection: 30 % of available detections for line 64 cannot be used for reconstructing scheduled trips. An example follows: the day 9/3/1999 2457 detections have been produced for buses showing line 64. But, according to the schedule, only 1708 detections were expected, because: 61 were the planned trips for each direction of the line and 14 detectors are located along each direction of the line. Two important issues came out:
- why so many "useless" detections have been produced?
- how to recognize and discard all of them?

Reasons why useless detections might be produced

The analysis of the Detection Database led us to envision three main kinds of useless detections:
A. Detections which contain mistakes,
B. Redundant detections of the same vehicle,
C. Detections coming from unreliable detectors.

A. Detections which contain mistakes. What mistakes might be found in a detection? Let's remember the content of a detection in the table below.

<table>
<thead>
<tr>
<th>TIME OF DETECTION</th>
<th>DETECTOR IDENTITY</th>
<th>TRANSPONDER SETTINGS OF DETECTED BUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day, Time</td>
<td>Intersection, Loop</td>
<td>Kind of service, Line number, Driver daily shift</td>
</tr>
</tbody>
</table>

- Time of detection: we expect that the time-stamping machine makes no mistakes.
- Detector identity: the observation of some days detections let us expect that also this data are correct.
- Transponder settings on the contrary could be misproduced, misunderstood or badly set up by the driver. The last case occurs when the driver forget to update the line number when starting a service on a different one. It happens also when the bus runs not in service and keeps the last trip settings.

B. Redundant detections of the same vehicle. Sometimes a detector produces more than one detection of the same vehicle in very few seconds. Just one of the detections is needed for reconstructing the trip. Tab 2.2 shows an instance for line 64 route 2. See loop 0 of the intersection 2.

C. Detections coming from unreliable detectors. Most of the useless detections for line 64 is due to the unreliable operation of detectors of the group 99. Every time a bus enter the group 99 area a confusing and unreliable sequence of detections is produced. An explanation follows. Over there many loops are located between platforms for passengers. Distances are so short that more than one detector detects the vehicle. This kind of undesired detections concerns not only line 64 but all the lines in Delft, because all of them stop at Station Centrum. (See table 2.1 and 2.2 for line 64, both the routes) As a temporary

4 This matter concerns, more or less, all the bus lines in Delft.
5 "Useless detections" is used for those detections which are not usable for reconstructing scheduled trips.
6 Station Centrum bus terminal
Discarding excess detections for a bus line

Discarding excess detection for a bus line requires two steps:
- the human analysis of the Detection Database for the selected bus line, in order to find and exclude unreliable detectors. (Useless detections of type C);
- the development of a procedure for the automatic acknowledgement and discarding of useless detections of type A and B.

7 Only loop 99 12 has been “saved”. It provides indeed reliable detections, probably because it is far from all the other loops.
3 Selecting detections for reconstructing scheduled trips

What do we mean for trip reconstruction from available detections? How did we realize a software which selects detections usable for the trip reconstruction? An answer to these two questions is provided in this chapter.

3.1 Graphic reconstruction of a scheduled trip

A graphic example of trip reconstruction is illustrated in figure 3.1. A bus line and route are selected and the sequence of detectors and bus stops is shown in the horizontal axis. A day and some scheduled trips, executed by the same bus driver, have been chosen. The schedule times at stops and the observed times at detectors are indicated by means of solid circles and empty squares respectively.

Reconstructing a scheduled trip in the graph could be imagined as choosing only detections which are “close enough” to the trip. Displaying detections only for a selected day, line, route and driver make easier to chose the correct detections for the trip reconstruction. Thanks to the selection of line and driver numbers, detections showing “impossible” transponder codes are excluded. Type C detections (coming from unreliable detectors) have been also excluded, therefore the remaining useless detections in the graph are:
- redundant detections. (Type B). See the 2nd detection of the 4th detector. No problem is brought to the trip reconstruction;
- detections of buses not in service which show the last trip settings of the transponder code. (Type A). Look at the last detection of the 1st detector for an instance;
- other detections with a mistake in the transponder code like the 3rd one of the 3rd detector. (Type A). This is a very strange one because it is impossible that the same vehicle is detected in different places at the same time (09:35). The graphic choice between the 3rd and the 4th detection of detector 3 is clear. The choice of the 4th detection would bring to negative driving times in the section between 2nd and 3rd detector. Actually rare cases have been found of such a strange mistake.

A graphic example of trip reconstruction is very useful for making an idea of the problem, but actually the a procedure for the automatic trip reconstruction is our task. The procedure is requested to acknowledge what trip a detection can be referred to.

---

Figure 3.1 – Graphic reconstruction of a scheduled trip

---

8 A transponder code is “impossible” when the bus line number or driver shift number or their combination does not exist in the timetable.
3.2 Condition for a detection to match with a scheduled trip

The condition for a detection to match with a scheduled trip was conceived with the consideration of the following issues (see again figure 3.1):

1) are detections to be compared with the schedule times at detector’s adjacent stops?
2) how close must be a detection to the schedule times of a trip to match with it?
3) when a detector produces two or more detections matching with the same scheduled trip: which one is to be used?

1) Our solution avoided a comparison between times referring to different points of the bus line. See figure 3.2. Linear interpolation has been used to determine the expected time at detector position (the crosses). In the light of this, a condition has been defined for a detection to match with a scheduled trip. Here it is. Selected a day, line, route and driver to refer to: a detection matches with one of the scheduled trips only when it exist at least a scheduled trip for which

\[
\text{DetectedTime(detector)} - \text{ExpectedTime(detector, scheduled trip)} \in [\text{Time range for the match}]
\]

2) The time range for the match is the limit to the acceptable deviation of a detected time from a schedule time for finding a match. The range extremes for line 64 are: -5 and +10 minutes i.e. a detection matching with a trip must not be earlier than 5 minutes and later than 10 than the expected time. Asymmetry of the interval was chosen with the consideration that a bus is more likely to be late than early at bus stops. The range width depends on the kind of bus line, a 15 minute one has been chosen for line 64 which is an urban line. Assumptions made in points 1 and 2 allow to discard most of the useless detections of type A.

3) Sometimes two or more detections are produced by one detector and both of them match with the same scheduled trip. We assumed that only the closest one to the schedule matches the trip. Let’s see what are the consequences of this assumption. In most of the cases detections are produced in few seconds (useless detections of type B), therefore the choice of one or another implies an irrelevant mistake. In very few cases detections are produced after some minutes, look at the case shown in figure 3.1. The first of the two detections is wrong (useless detections of type A). In cases like this, the adopted rule could lead to chose the wrong detection.

As to useless detections of type C, they have been discarded in a simple way: unreliable detectors are not included among detectors of line 64. The mentioned criteria allow to discard, most of type A and all type B and C useless detections.

![Figure 3.2 - Condition for a detection to match with a scheduled trip. This figure is an excerpt of figure 3.1 and shows detected times for just a detector and scheduled time for the two adjacent bus stops.](image-url)
3.3 The implemented software package for the trip reconstruction

In order to create a program for reconstructing scheduled trips, all elements displayed in the distance time graph (figure 3.2) had to be described in file format and collected in databases.

- Stop/detector positions and identities have been collected for every line in a file of the Line Description Database (LD DB). Table 3.1.
- Detections were already included in the Detection Database day-files (DET DB). Table 3.2
- Schedule times at stops were already collected in the Time-Table Database (TT DB). Table 3.3

<table>
<thead>
<tr>
<th>Bus stop module</th>
<th>Line</th>
<th>Route</th>
<th>Length [m]</th>
<th>Detectors of the module: Identity and Dist. from origin stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Origin stop</td>
<td>Dest. stop</td>
<td></td>
<td>First</td>
<td>Second</td>
</tr>
<tr>
<td>54267310</td>
<td>54263390</td>
<td>64</td>
<td>1</td>
<td>444</td>
</tr>
<tr>
<td>54263390</td>
<td>54263370</td>
<td>64</td>
<td>1</td>
<td>390</td>
</tr>
<tr>
<td>54263370</td>
<td>54263350</td>
<td>64</td>
<td>1</td>
<td>255</td>
</tr>
<tr>
<td>54263350</td>
<td>54263330</td>
<td>64</td>
<td>1</td>
<td>352</td>
</tr>
<tr>
<td>54263330</td>
<td>54262550</td>
<td>64</td>
<td>1</td>
<td>618</td>
</tr>
<tr>
<td>54262550</td>
<td>54262440</td>
<td>64</td>
<td>1</td>
<td>598</td>
</tr>
<tr>
<td>54262440</td>
<td>54260480</td>
<td>64</td>
<td>1</td>
<td>323</td>
</tr>
<tr>
<td>54260480</td>
<td>54261507</td>
<td>64</td>
<td>1</td>
<td>635</td>
</tr>
<tr>
<td>54261507</td>
<td>54261592</td>
<td>64</td>
<td>1</td>
<td>906</td>
</tr>
<tr>
<td>54261592</td>
<td>54261650</td>
<td>64</td>
<td>1</td>
<td>655</td>
</tr>
<tr>
<td>54261650</td>
<td>54264760</td>
<td>64</td>
<td>1</td>
<td>411</td>
</tr>
<tr>
<td>54264760</td>
<td>54261900</td>
<td>64</td>
<td>1</td>
<td>556</td>
</tr>
<tr>
<td>54261900</td>
<td>54261880</td>
<td>64</td>
<td>1</td>
<td>475</td>
</tr>
<tr>
<td>54261880</td>
<td>54261920</td>
<td>64</td>
<td>1</td>
<td>348</td>
</tr>
<tr>
<td>54261920</td>
<td>54261840</td>
<td>64</td>
<td>1</td>
<td>372</td>
</tr>
<tr>
<td>54261840</td>
<td>54261860</td>
<td>64</td>
<td>1</td>
<td>438</td>
</tr>
</tbody>
</table>

Table 3.1 Line Description Database. This is an extract for line 64 route 1.

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>Detector</th>
<th>Service</th>
<th>Line</th>
<th>Driver or Trip shift</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999Mar 1</td>
<td>8.48.32</td>
<td>79 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>8.52.21</td>
<td>77 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>8.55.59</td>
<td>30 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>8.58.15</td>
<td>99 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>8.58.23</td>
<td>99 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.02.14</td>
<td>99 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.02.15</td>
<td>99 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.02.17</td>
<td>99 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.02.18</td>
<td>22 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.02.21</td>
<td>99 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.02.23</td>
<td>99 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.02.35</td>
<td>22 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.03.49</td>
<td>6 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.05.01</td>
<td>6 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.06.06</td>
<td>6 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.07.51</td>
<td>10 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.08.12</td>
<td>10 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
<tr>
<td>1999Mar 1</td>
<td>9.10.31</td>
<td>60 U</td>
<td>streekdienst</td>
<td>lijn 64</td>
<td>vlg 14</td>
</tr>
</tbody>
</table>

Table 3.2 - Detection Database. A depiction of this database has already be made in Table 1.1. The only difference is that detections have been aggregated for one driver and line. The meaning is the following: the 1st March 1999 the bus driver with the trip shift #14 has executed a trip on line 64, route 1 (from detector 79 1 to 60 3) in a period between 08:48 and 09:10.
Table 3.3 Time Table Database. This is the schedule corresponding to the trip detection shown in Table 3.2. Let’s illustrate the correspondence.

- The schedule is valid for working days from Monday to Friday. (The 1st March 1999 is a Monday).
- The line (64), route (1) and driver (14) numbers are the same.

**Automatic selection for one day, line and route: main steps**

Let’s see now how the databases are used by the programs developed for one day, line and route reconstruction of a trip.

- One day, line and route are chosen, and the corresponding files of the DBs are used.
- Three programs access the databases and compare detections with schedule in order to associate detection to trips. See table 3.4 (r=read, w=write)
- As a result a new database, called TRITAPT, collects schedule and observed times of every planned trip on a bus line. Also the bus line description is included in the TRITAPT DB, therefore usually there is no more reason to refer to the other three databases. Table 3.5 illustrates the Tritapt DB contents.

<table>
<thead>
<tr>
<th>PROGRAM</th>
<th>ACCESSED DBs</th>
<th>SCOPE</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Zwn.c</strong></td>
<td>Time Table (r)</td>
<td>The program uses the scheduled times at stops (TT DB) and the bus line</td>
</tr>
<tr>
<td></td>
<td>Line Description (r)</td>
<td>description (LD DB) for interpolating the scheduled times at detectors.</td>
</tr>
<tr>
<td></td>
<td>Tritapt (w)</td>
<td>Scheduled times at detectors are stored in the Tritapt DB file</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(for the same [Day Line Route] which are selected).</td>
</tr>
<tr>
<td><strong>Matchdet.c</strong></td>
<td>Detection (r)</td>
<td>This program compares each detection (DET DB) with the schedule times at detectors (Tritapt DB) and looks for a match.</td>
</tr>
<tr>
<td></td>
<td>Tritapt (r)</td>
<td>Only matching detections are appended to the Tritapt file.</td>
</tr>
<tr>
<td></td>
<td>Tritapt (w)</td>
<td>Observed times at stops are appended to the Tritapt DB file.</td>
</tr>
<tr>
<td><strong>Det2stop.c</strong></td>
<td>Tritapt (r)</td>
<td>It uses the times of matching detections (Tritapt DB) and the bus line description (LD DB) for interpolating the &quot;observed&quot; times at bus stops.</td>
</tr>
<tr>
<td></td>
<td>Line Description (r)</td>
<td>Observed times at stops are appended to the Tritap DB file.</td>
</tr>
<tr>
<td></td>
<td>Tritapt (w)</td>
<td></td>
</tr>
</tbody>
</table>

Table 3.4 – The software for the automatic selection of detections matching with the time table.
<table>
<thead>
<tr>
<th>Bus stop #</th>
<th>Absolute Code</th>
<th>Bus stop name</th>
<th>Abbrev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54267310</td>
<td>0 Abtswoudepark</td>
<td>AP</td>
</tr>
<tr>
<td>2</td>
<td>54263390</td>
<td>44 Rietzangerstraat</td>
<td>RS</td>
</tr>
<tr>
<td>3</td>
<td>54263370</td>
<td>83 Fuulaan</td>
<td>FL</td>
</tr>
<tr>
<td>4</td>
<td>54263350</td>
<td>109 Edelhertlaan</td>
<td>EL</td>
</tr>
<tr>
<td>5</td>
<td>54263330</td>
<td>144 Kalfjeslaan</td>
<td>KL</td>
</tr>
<tr>
<td>6</td>
<td>54262550</td>
<td>206 J. Campertlaan</td>
<td>JC</td>
</tr>
<tr>
<td>7</td>
<td>54262440</td>
<td>266 In de Hoven</td>
<td>IH</td>
</tr>
<tr>
<td>8</td>
<td>54260480</td>
<td>318 Krakeelpolderweg</td>
<td>KW</td>
</tr>
<tr>
<td>9</td>
<td>54261507</td>
<td>382 Station Centrum</td>
<td>SC</td>
</tr>
<tr>
<td>10</td>
<td>54261592</td>
<td>472 In de Veste</td>
<td>IV</td>
</tr>
<tr>
<td>11</td>
<td>54261650</td>
<td>538 M. de Ruiterweg</td>
<td>MR</td>
</tr>
<tr>
<td>12</td>
<td>54264760</td>
<td>579 Oostplein</td>
<td>OP</td>
</tr>
<tr>
<td>13</td>
<td>54261900</td>
<td>634 Poortcenter</td>
<td>Po</td>
</tr>
<tr>
<td>14</td>
<td>54261880</td>
<td>682 IKEA</td>
<td>IK</td>
</tr>
<tr>
<td>15</td>
<td>54261920</td>
<td>717 Grote Beer</td>
<td>GB</td>
</tr>
<tr>
<td>16</td>
<td>54261840</td>
<td>754 Kinderboerderij</td>
<td>Ki</td>
</tr>
<tr>
<td>17</td>
<td>54261860</td>
<td>798 Delftse Hout</td>
<td>DH</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Bus Stop</th>
<th>Observed time</th>
<th>Schedule time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>#</td>
<td>arr.</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>31700</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>31879</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>31813</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>31769</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>32155</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>32037</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>32282</td>
</tr>
<tr>
<td>8</td>
<td>8</td>
<td>32223</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>32402</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
<td>32634</td>
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<td>11</td>
<td>11</td>
<td>32878</td>
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<td>12</td>
<td>32978</td>
</tr>
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<td>15</td>
<td>33225</td>
</tr>
<tr>
<td>16</td>
<td>16</td>
<td>33285</td>
</tr>
<tr>
<td>17</td>
<td>17</td>
<td>33345</td>
</tr>
</tbody>
</table>

Table 3.5.1 TRITAPT Database. It contains elements of the three basic databases (LD, DET, TT DBs). This table shows the part which deals with the Line Description DB. Another table follows.

Table 3.5.2 TRITAPT Database. This other table shows the part which deals with Time Table DB and Detection DB (Only useful detections!). When a match is not found a "-1" mark is used. The knowledge about the presence or absence of expected detections for a trip is very important. Some interesting applications are the subject of the next chapter.

* Time is computed in seconds since midnight.

### 3.4 Programs which use selected detections

Two further programs can access the TRITAPT DB files. They are used for the analysis of selected detections:
- the "Matrix.c" analyses the availability of detections used for reconstructing a scheduled trips.
- the "TRITAPT" software package is used for the trip time analysis.

A description of the two programs and the results for bus line 64 are shown respectively in chapter 4 and 5.
4 Analysis of the availability of detections for a trip

As seen in table 3.5, a Tritapt database file for a selected day, line, route, shows for every scheduled trip and for every detector of the line, the availability of detections usable for reconstructing the trip. A daily and a multiple day use of this knowledge has been made and results for line 64 are illustrated in this chapter.

4.1 Daily analysis

4.1.1 The daily table of matches

The Matrix.c is the program developed for the daily analysis. It is run for a selected day, line, route and accesses the correspondent Tritapt DB file. In particular it checks the availability of expected detections for the scheduled trips and collects results in a table: the Daily table of matches. An example for the day 01/03/1999, line 64, route 1 is illustrated in table 4.1. A number of 14 columns and 61 rows make the table, because of the 14 detectors along the line and of the 61 scheduled trips for the selected day. Every trip is labelled with the departure time at the first stop. Three symbols are in the cases:
- a cross indicates match found,
- a dot indicates match not found,
- a % mark indicates match not to be searched, because that route is planned to be shorter than the whole route. The only case we found concerns the trips departing at 6:20. The last stop is Station Centrum therefore the last expected detection comes from detector 99 12.

<table>
<thead>
<tr>
<th>Date: 1999 03 01</th>
<th>Line: 64</th>
<th>Route: 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector group, loop number</td>
<td>Trip</td>
<td>Dep. time</td>
</tr>
<tr>
<td>------------------</td>
<td>-------</td>
<td>-----------</td>
</tr>
<tr>
<td>0</td>
<td>6.20</td>
<td>X X X X .</td>
</tr>
<tr>
<td>1</td>
<td>6.33</td>
<td>.</td>
</tr>
<tr>
<td>2</td>
<td>6.48</td>
<td>.</td>
</tr>
<tr>
<td>3</td>
<td>7.03</td>
<td>x x x X x X</td>
</tr>
<tr>
<td>4</td>
<td>7.18</td>
<td>x X x X X X</td>
</tr>
<tr>
<td>5</td>
<td>7.33</td>
<td>.</td>
</tr>
<tr>
<td>6</td>
<td>7.48</td>
<td>X X X X X</td>
</tr>
<tr>
<td>7</td>
<td>8.03</td>
<td>x X X X X</td>
</tr>
<tr>
<td>8</td>
<td>8.18</td>
<td>x X X X X</td>
</tr>
<tr>
<td>9</td>
<td>8.33</td>
<td>.</td>
</tr>
<tr>
<td>10</td>
<td>8.48</td>
<td>X X X X</td>
</tr>
<tr>
<td>11</td>
<td>9.03</td>
<td>x X X X</td>
</tr>
<tr>
<td>12</td>
<td>9.18</td>
<td>X X X X</td>
</tr>
<tr>
<td>13</td>
<td>9.33</td>
<td>X X X X</td>
</tr>
<tr>
<td>14</td>
<td>9.48</td>
<td>.</td>
</tr>
<tr>
<td>15</td>
<td>10.03</td>
<td>X X X X</td>
</tr>
<tr>
<td>16</td>
<td>10.18</td>
<td>X X X X</td>
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<tr>
<td>17</td>
<td>10.33</td>
<td>X X X X</td>
</tr>
<tr>
<td>18</td>
<td>18.18</td>
<td>X X X X</td>
</tr>
<tr>
<td>19</td>
<td>18.33</td>
<td>X X X X</td>
</tr>
<tr>
<td>20</td>
<td>18.50</td>
<td>X X X X</td>
</tr>
<tr>
<td>21</td>
<td>19.20</td>
<td>X X X X</td>
</tr>
<tr>
<td>22</td>
<td>19.50</td>
<td>X X X X</td>
</tr>
<tr>
<td>23</td>
<td>20.20</td>
<td>X X X X</td>
</tr>
<tr>
<td>24</td>
<td>20.50</td>
<td>X X X X</td>
</tr>
<tr>
<td>25</td>
<td>21.20</td>
<td>X X X X</td>
</tr>
<tr>
<td>26</td>
<td>21.50</td>
<td>.</td>
</tr>
<tr>
<td>27</td>
<td>22.20</td>
<td>X X X X</td>
</tr>
<tr>
<td>28</td>
<td>23.20</td>
<td>X X X X</td>
</tr>
<tr>
<td>29</td>
<td>23.50</td>
<td>X X X X</td>
</tr>
</tbody>
</table>

| fm(det) | 37 44 16 44 39 44 43 38 43 31 42 40 43 32 | Regular trips 44 |
| St -um(det) -It | 44 44 44 44 44 44 43 43 43 43 43 43 43 43 | Scheduled trips 61 |
| rfm(det) | 84 100 36 100 88 100 100 88 100 72 97 93 100 74 | rate 72 |

Table 4.1 - Daily table of matches.
4.1.2 Possible uses for the daily table of matches

Basic ideas and related problems
Two basic ideas for using this table were the following: the count of found matches for a trip and the count of found matches for a detector.

a) the count of found matches for a trip could be used to decide whether a trip was executed or not. Table 4.1 is again used. The result is evident for trips starting at 6:33 or 6:48 for instance, no match is found and the trip seems to have been skipped. The result is also clear for trips departing at 6:20 or 7:03 or 7:18 hours. An high fraction of the expected matches is found. Some hesitation arrives when the number of found matches for trip is low. Consider trips starting at 8:33 and 18:50. Two extreme situations could be:
   - the trip was run just for a part of the bus line therefore the trip incompleteness is the cause of missing detections, otherwise
   - the trip was run for the whole route and the missing detections come from: bad operation of some detectors, or transponder failures for instance.
   As a consequence, not all missing matches for a trip derive from trip incompleteness.

b) the count of found matches for a detector could be used for assessing the performance of a detector. But also in this case not all missing matches for detector derive for sure from a detector failure; a transponder could have failed or a wrong transponder code set or, most awfully, a trip could have been incomplete.

Adopted solutions
a) In order to assess whether a trip was executed or not from the count of found matches for the trip, one should be sure that all missing matches for the trip derive from the trip incompleteness. We assumed a trip to be “non executed” or “irregular” only when the number of found matches is zero:

\[ fm(trip) = 0 \]

Higher values like 2 or 3 (for line 64) could have been chosen, but were not. In fact, the doubt whether bus transponder failures together with detector failures have caused the lack of matches could be used by the public transport company to criticize the trip irregularity assessment.

b) In order to assess the detector performance from the count of found matches for the detector, one should be sure that all missing matches derive from the detector failures. This are our assumptions:
   - missing matches at a detector, which were caused by trip irregularity can be recognized (\( fm(trip)=0 \)), and must be subtracted from the total of expected detections;
   - the remaining missing matches at a detector can be due to detector or bus transponder failures. Only a deeper analysis (also of useless detections) could provide an answer. Therefore missing matches for detector have been called “failures occurring at detectors” instead than “detector failures”.
   The daily parameter for the failures occurring at a detector is called “rate of found matches for detector” and it is defined as follow:

\[ rfm(det) = \frac{100 \cdot fm(det)}{St - um(det) - It} \]

\( rfm(det) \) rate of found matches for detector  
\( fm(det) \) found matches for detector  
\( St \) scheduled trips for the line  
\( um(det) \) unexpected matches for detector (or number of cases showing “%” for that detector)  
\( It \) irregular trips and so matches that cannot be found  
All these parameters refer to one day.

c) Another use of the number of found matches for trip has been conceived. On the basis of the distribution of detectors along line 64 route 01 it was assumed that: a trip can be used for time analysis only when:

\[ fm(trip) \geq 10 \]
Limiting missing matches for a trip corresponds to reduce errors for interpolated times at bus stops. This limit value depends on the number and location of detectors along the line, therefore it is to be defined for both routes of each bus line.

<table>
<thead>
<tr>
<th>Usability for time analysis</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regularity</td>
<td>No</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>fm(trip)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.1 displays for line 64 route 1 the two limit values introduced for fm(trip).

On the basis of the three definitions above, the daily table of matches was enriched with some elements among which:
- Found matches for trip 
- “Irregular” label for every trip with fm(trip) = 0
- “Not usable” label for every trip with fm(trip) ≤ 10
- Rate of found matches for detector rfm(det)

### 4.2 Multiple day analysis

The multiple day analysis was made by introducing two other tables:
- Table of found matches for trip - fm(trip), used for the trip regularity assessment
- Table of found matches for detector - rfm(trip), used for the detector performance control

Values for these tables are taken from several Daily tables of matches. The information flow is depicted in figure 4.2.

Figure 4.2 Table of fm(trip) and Table of rfm(det) from the daily Table of found matches
4.2.2 Table of found matches for trip – \( fm(trip) \)

The table uses as many columns as there are days in the chosen sample. (All working days of March 1999 for line 64 route 1). Each column shows the \( fm(trip) \) for the trips of one day. Several kinds of graphs have been extracted from the Table, some of them are here included. Figure 4.3.A shows the frequency of \( fm(trip) \) while figure 4.3.B shows the cumulative distribution of frequency. What can be extracted from these graphs is that:

- 8% of scheduled trips was not observed at all, and appear to be irregular;
- 16% of the trips have been detected between 1 and 9 times of 14, some problems concern the trip observability;
- 76% of the trips have been detected well enough for trip time analysis.

<table>
<thead>
<tr>
<th>Line: 64</th>
<th>From: Abtswoondepark</th>
<th>Selected days: March 99</th>
<th>Detector: —:—</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route: 1</td>
<td>To: Delfse Hout</td>
<td>Day types: Mo =&gt; Fri</td>
<td>Trip dep.time: —:—</td>
</tr>
</tbody>
</table>

**Figure 4.3.A** – Frequency of found matches for trip.

**Figure 4.3.B** – Cumulative distribution of frequency for found matches for trip.

The frequency of \( fm(trip) \) for trips departing at the same time are illustrated in figure 4.4.A, B, C for three departure times. Here follow the results:

- excellent results, like most of the observed trips, were found for 08:48 trips. Figure 4.4.A.
- good results with high percentage of trips usable for time analysis have been found for the 10:48 trips. 5% cases show some problems occurring at detectors. But 13% irregular trips should be reduced. See figure 4.4.B.
- the worst result one could expect was found just once (see the 06:48 trips in figure 4.4.C). No one of the expected detections seem have been produced. Actually this case was too suspect to be true. In fact it was found that the electronic time table contains number 75 as driver code, while the timetable given to drivers and used for the transponder indicates number 35. As a consequence detections are interpreted as wrong by the procedure which looks for a match with the electronic timetable. Once the mistake is fixed, the 6:48 trip regularity assessment will not be so severe!
Figure 4.4.A – Frequency of fm(trip) for trips departing at 08:48

Figure 4.4.B – Frequency of fm(trip) for trips departing at 10:48

Figure 4.4.C – Frequency of fm(trip) for trips departing at 06:48
The number of irregular trips for every day is in figure 4.5: values vary in the days but no weekly pattern seems apparent.

<table>
<thead>
<tr>
<th>Line: 64</th>
<th>From: Abtwoudsepark</th>
<th>Selected days: March 99</th>
<th>Detector: --:--</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route: 1</td>
<td>To: Delftse Hout</td>
<td>Day types: Mo =&gt; Fri</td>
<td>Trip dep.time:--</td>
</tr>
</tbody>
</table>

**Daily irregular trips (end of scale = daily schedule trips)**

Figure 4.5 – Daily irregular trips

### 4.2.3 Table of rate of found matches for detector – rfm(det)

The table uses as many rows as there are days in the chosen sample. (All working days of March 1999 for line 64 route 1 are used in the example). Each row contains the rate of found matches for detectors -rfm(det) of one line for one day.

Most of detectors have performed in a rather satisfactory way, but further improvements are to be expected. A general vision of the average performance of all detectors of the line is performed in next figure where the mean rate of found matches of a detectors of a bus line is computed for the days of the chosen sample.

<table>
<thead>
<tr>
<th>Line: 64</th>
<th>From: Abtwoudsepark</th>
<th>Selected days: March 99</th>
<th>Detector: all</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route: 1</td>
<td>To: Delftse Hout</td>
<td>Day types: Mo =&gt; Fri</td>
<td>Trip: --:--</td>
</tr>
</tbody>
</table>

**Mean rfm(det)**

Figure 4.6 – The average performance of all detectors along line 64, route 1.

Detector performance for every day of the sample is illustrated in figures 4.7.A, B, C for three observed behaviours:

- **9912** shows an excellent performance, like most of the analysed detectors
- **7901** has usually shown rather high values, but for some days have been out of order.
- **3006** performs alternatively. It shows values which alternate between 50% and 80%.
Figure 4.7.A – Rate of found matches for detector 9912.

Figure 4.7.B – Rate of found matches for detector 7901.

Figure 4.7.C – Rate of found matches for detector 3006.
5. Analysis of trip times

Once detections of the Detection database have been selected for the trip reconstruction, two uses have been made:
- analysis of the availability of detections for a trip (discussed in chapter 4) and
- analysis of trip times, which is the subject of this chapter. The software in use and an application to line 64 follow.

5.1 The TRITAPT software

TRITAPT (TRlp Time Analysis in Public Transport) is a software package developed at TU Delft with the scope to analyse and improve the performance of public transport.

Reasons for its use in Delft

Several good reasons were found, such as:
- the number and kind of performance indicators available for the time analysis;
- the possibility to extract tables and graphs for all performance indicators. Furthermore graphs can be performed for selected days, day types and time of the day;
- the successful application of this software to the bus monitoring system in Eindhoven, also in The Netherlands;
- the possibility to refer directly to one of the software implementers.

Making Tritapt work for the Delft bus monitoring system

Triapt has been used the first time for the bus monitoring system in Eindhoven. Over there vehicle on board computers are used and a continuous trip detection is produced. On the contrary the system in Delft uses individual detectors on the roads. Therefore, as another task of the research, Triapt had to be adapted to “discrete” monitoring systems.

As a first step of the software adaptation, the results of the Detection Selecting Process (chapter 3) have been collected in a Triapt compatible format (Triapt DB). As a second step Triapt needed to distinguish detectors from bus stops or at least it should introduce detectors in the graphs. New important options for Triapt graphs have been created, such as:
- showing detectors in the distance axis
- using proportional spacing of stops and detectors.

Another new option for the software regards the automatic selection of trips to be used for the time analysis. The rule has been defined in chapter 4.

5.2 Trip time analysis for line 64

One day analysis as well as multiple day analysis can be performed with the help of Triapt graphs.
- One day analysis can be made by means of common distance-time diagrams. One sample is shown in figure 5.1. The horizontal axis uses proportional spacing and shows bus stops (two letter abbreviation of the bus stop name) as well as detectors (vertical dashes below the axis). The vertical axis is time of the day. Besides the graph usefully indicates whether a detection is available or not (circles are used in the negative case).

---

9 Given the satisfactory applicability of Triapt to discrete monitoring systems, a workshop on the Triapt usability for other bus monitoring projects is going to be organized in short time.
The most interesting analysis is the multiple days one. The Tritapt software performs graphs by which scheduled and observed trip times of a large set of days can be compared. As regards line 64, there are three different schedules, based on the type of day. Graphs for all of them have been extracted, but the most statistically relevant results have been found for the working days schedule. 105 working days of 21 weeks belonging to January up to May 1999 have been used for the graphs of the following four paragraphs.

An analysis of the trip times for line 64 route 1 in the period from January up to May 1999 is now reported. The followings steps are made:
- statistical analysis of the trip duration in the different hours of the day,
- individuation of periods of the day with similar trip duration (homogeneous periods-HP),
- study of the punctuality deviations at stops for every HP,
- suggestions for new passing moments at stops in order to have a more respectable schedule for every HP.

### 5.2.1 Traject times and homogeneous periods

#### Traject times

The traject time of a trip is its duration. Some statistics on the traject times in the hours of the day are illustrated in figure 5.2. The horizontal axis is labelled with the departure times of the schedule. The vertical axis instead shows the traject times. Grey boxes indicate the mean trip duration, while asterisks indicate that the 85% of the trips can complete the trip in that time and downwards arrows show the longest observed trip duration. Finally the horizontal blue line is the planned traject time. (All the trips of the day are expected to be completed in 23 minutes). This kind of graph allows to analyse whether sufficient time is scheduled as the trip duration.

#### Results for line 64

For most of departure times less than 50% of the trips can complete the service in the planned 23 minutes. Notice the 28 minutes for the average trip departing at 08:48. An evident implication is the 5 minute delay at the last stop!  
As expectable the time needed for completing the trip varies in the day. Periods with similar traject time (homogeneous periods) can be found. Tritapt helps defining them. With the aim to improve the correspondence between trip schedule and trip execution we will suggest a different schedule for every period.

---

10 The scheduled time which elapses between the beginning of two next services includes also some rest time. Thanks to the rest time a chain of delays is not generated for line 64.
Suggested periods based on observed net traject times (tolerance = 120s)

Company: Zwn
line: 064
Route: 01
Departure times Dates: 1999/01/04 until 1999/05/21
from: Abtswoudsepark from: 00:00 Mon Tue Wed Thu Fri Sat Sun Total
until: 30:00 20 20 20 20 20 0 0 100
Trips scheduled: 6000
Trips used: 3668 (61%)
Trips excluded: 3 (0%)

Departure times:


MLT
**Homogeneous periods**

An homogeneous period is a period of the day where trips are usually completed in a similar time. Figure 5.2 is used again. For each departure time one, or two, horizontal blue boxes are located around the 85% value with a tolerance. Some human judgement is required for the number and boundaries of homogeneous periods to choose. Tritapt can use several tolerance values for the graph and, playing with some of them provide a wide sample where to chose. The traject time indicated for a period corresponds to the time which could guarantee about the 85% feasibility of the time-table. As to line 64 four homogeneous periods have been defined:

- from 00:00 to 07:30 early morning
- from 07:30 to 09:00 morning rush
- from 09:00 to 20:00 rest of the day
- from 20:00 to 24:00 night. (Actually also the past midnight trips are included in this period by the Tritapt).

Once an homogeneous period is defined, all its trips are used for the analysis of the observed passing moments at bus stops. A useful comparison between observed and scheduled passing moments is performed by the Punctuality Deviation graph.

### 5.2.2 Punctuality deviation at stops: the graph

**The graph**

The punctuality deviation at a bus stop is the difference between observed and scheduled passing time at the stop.\(^{11}\)

\[
Pd (\text{stop, trip}) = \text{ObsTime(}\text{stop,trip}\text{)} - \text{SchedTime(}\text{stop,trip}\text{)}
\]

Two graphs are illustrated in figure 5.3.A and 5.3.B. They refer to the chosen bus line, route, days and trips of the morning and night HP. The horizontal axis shows the sequence of stops and detectors of the line. (Two letter abbreviation for the stop names and a number for detectors). Proportional spacing is used in the distance axis. The vertical axis shows the punctuality deviation in minutes. For positive values the bus is late at stop, otherwise the bus is early or in time.

For the selected set of trips Tritapt computes the 15%, 50% and 85% punctuality deviations at bus stop. (Pd\(_{15}\), Pd\(_{50}\), Pd\(_{85}\)). The meaning is that 15%, 50% and 85% of the trips has a smaller deviation from punctuality. Three windings bold lines are used in the graph.

- The middle one connects the Pd\(_{50}\) values calculated at each bus stop
- the top one uses Pd\(_{85}\) while
- the bottom one uses Pd\(_{15}\).

Two further (thin) lines are used: the top one connects the largest Pd recorded at stops, while the bottom one uses the smallest Pd.

**A desirable trend**

A good trend for the bold curves would show:
- a flat Pd\(_{85}\) line (rather close to zero) and
- a small standard deviation for the Pd. That coincides with a short distance between Pd\(_{85}\) and mean value (or between Pd\(_{15}\) and the mean).\(^{12}\)

---

\(^{11}\) In chapter 3 a closeness condition has been defined for observed and scheduled times in order to find a match. For line 64 the interval for the match begins 5 minutes before the schedule time and ends 10 minutes later. Therefore Pd is expected to be included between -5 and +10 minutes.

\(^{12}\) A normal distribution approximates the Pd distribution, therefore \(\text{Mean}(\text{Pd}) \pm \text{stdev}(\text{Pd}) \approx \text{Pd}_{85}, \text{Pd}_{15}\).
Figure 5.3.A – Punctuality deviations in the morning

Figure 5.3.B – Punctuality deviations in the night
5.2.3 Punctuality deviation at stops: results for line 64

The morning and the night punctuality deviation values are illustrated in figures 5.3.A and 5.3.B. A first sight at the two diagrams allows to distinguish four sections of the line:
- before Station Centrum SC, (AP-5);
- around SC, i.e. between detectors 5 and 6, respectively at the entrance and exit of the bus terminal area (5-6);
- behind SC up to the last detector, (SC-13);
- the undetected part of the line, (13-DH).

The undetected part of the line, (13-DH)

The situation: Given the lack of detections, we assumed that buses respect the schedule, therefore a plate trend is shown.

Suggestions: Provide the end of the line with a detector allows computing a more reliable traject time. As an implication the bus company could better optimize the use of its resources! Or else drivers could have an evidence that the time for rest is shorter than agreed.

Before Station Centrum SC, (AP-5)

The situation: It must be remarked that only one schedule is used for all the hours of the day, therefore deviations from schedule times (or Pds) are expected to vary between the morning and the night trips. In the morning the mean trip begins quite on time and Pd» keeps close to zero up to the end of the section. Therefore in the morning the average trip respects the schedule. In the night the Pdso curves begin just one minute late but decreases so that even trips departing 2 minutes late arrive early at the SC entrance. The main reason is not related to the traffic influence. The reserved lanes and priority at intersections in use make this influence irrelevant and constant in the hours. An evidence is provided by the standard deviation trend. It keeps remarkably small (one minute) along the section and it does not vary between morning and night. The more likely reason can be seen in a “service rule” which is more frequently applied in the night. Drivers are allowed to “skip” a bus stop when no passenger requests to board or alight at the stop.

Suggestions: Create a night schedule allowing less time to complete this part of the trip. For a suggestion about the new passing times at stops refer to paragraph 5.2.4.

Around SC, (5-6)

The situation: In the morning on average buses arrive on time at the SC entrance, but depart 2 minutes late, thus spending 3 minutes for boarding and alighting passengers. (One minute of the three is the scheduled waiting time at SC). Two questions follow:
- Is this delay expectable? Given the big importance of this exchange area for passengers only one minute is clearly insufficient.
- How much time drivers really need? A look at the standard deviation trend helps to answer. The 50% trip reveals that on average drivers act as they needed 3 minutes. Actually also the 15% and the 85% curves show a two minutes jump for Pd. It means that most of the drivers in the morning need right 3 minutes at SC. As a consequence it is advisable that the morning schedule allows 3 minutes at the SC terminal.

In the night a different trend is shown. On average buses arrive two minutes before than scheduled and depart one minute late, thus spending 4 minutes. Two explanations for this mean behaviour follow: the schedule allows too much time in the previous section. A “service rule” valid only at SC prevents drivers from departing before than scheduled. As a consequence on average buses spend more time than in the morning at SC! The actual need is for sure less than the current 4 minutes. This is revealed also from the different times spent by the 15% and 85% trips, respectively 3 and 4.5 minutes.

13 Labels for stop and detectors are not clear yet, we apologise for this.
14 Trains, trams of line 1, several taxis and 13 bus lines met in this area.
Suggestions: In the morning some more time must be scheduled at SC. Three minutes would suit the boarding and alighting needs; more than three minutes could be planned for improving coincidences. As regards the night schedule the first step to do is the improvement of the time-table for the section AP-5. Than, more than one minute (current situation) should be scheduled at SC.

Behind SC up to the last detector, (SC-13)
The situation: In the morning on average buses leave the SC terminal 2 minutes late and increase the delay up to 4 minutes. In the night instead buses depart with one minute delay, but soon go on schedule, up to the end. It is evident that in the morning insufficient time is computed for completing this part of the trip, while in the night the schedule is quite perfect. Like in (AP-5), the slope of the Pd curves reduces in the night (more possibility to catch up the schedule). In both sections the possibility to “skip” several bus stops in the night has a big influence, but in section (SC-13) a further reason is the reduction of traffic influence in the night. Contrary to (AP-5) this section has not reserved lanes and priority at intersections and the traffic influence vary a lot between morning and night. Notice how the standard deviation is bigger and increases in the morning and is small and constant in the night.

Suggestions: Give more time in the morning schedule and keep the current time-table in the night. For a suggestion of new passing moments at stops see paragraph 5.2.4.

5.2.4 Suggestions for new passing moments at bus stops

Passing moment at a bus stop is the time which elapses from the beginning of the trip up to the arrival of the bus at the considered stop. Suggestions for new passing moments at bus stops conclude this trip time analysis. Suggestions are performed by the Tritapt software for about 85% feasibility of the time-table and results for the morning and night homogeneous periods are shown in figures 5.5.A and 5.5.B.

As a general rule it is advisable to assess the adequacy of automatically computed passing moments. We have found that a suitable instrument is a detector-to-detector analysis of the Pd graphs. Of course an on field knowledge of the line and the direct observation of some trip executions are required.

Conclusions

In order to conclude the trip time analysis let’s briefly summarize the steps we have followed.
- Traject times and punctuality deviation graphs have shown that the time-table is not respected in some hours of the day and in some parts of the line.
- The analysis of the trip duration has brought to define some homogeneous periods (HP) of the day as suggestions for periods with different schedules.
- For every HP the analysis of the Punctuality deviation at bus stops has allowed to find the points of the line where delays are produced respect to the current time-table.
- As the last step passing moments at stops have been computed for every proposed time-table.
### Figure 5.4.A – Suggested passing moments for the morning schedule

**Passing moments (Feasibility = 82%, net time = 28:00 minutes)**

<table>
<thead>
<tr>
<th>Company</th>
<th>Route: 01</th>
<th>Departure times</th>
<th>Dates: 1999/01/04 until 1999/05/21</th>
<th>Trips scheduled: 600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zwn</td>
<td>from: Abtswoudsepark</td>
<td>from: 07:30</td>
<td>Mon Tue Wed Thu Fri Sat Sun Total</td>
<td>Trips used: 397 (66%)</td>
</tr>
<tr>
<td>Line: 064</td>
<td>to: Delftse Hout</td>
<td>until: 09:00</td>
<td>20 20 20 20 20 0 0</td>
<td>100 Trips excluded: 12 (2%)</td>
</tr>
</tbody>
</table>

![Diagram showing suggested passing moments for the morning schedule](image)

### Figure 5.4.B – Suggested passing for the night schedule

**Passing moments (Feasibility = 73%, net time = 23:00 minutes)**

<table>
<thead>
<tr>
<th>Company</th>
<th>Route: 01</th>
<th>Departure times</th>
<th>Dates: 1999/01/04 until 1999/05/21</th>
<th>Trips scheduled: 800</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zwn</td>
<td>from: Abtswoudsepark</td>
<td>from: 20:00</td>
<td>Mon Tue Wed Thu Fri Sat Sun Total</td>
<td>Trips used: 221 (28%)</td>
</tr>
<tr>
<td>Line: 064</td>
<td>to: Delftse Hout</td>
<td>until: 30:00</td>
<td>20 20 20 20 20 0 0</td>
<td>100 Trips excluded: 21 (3%)</td>
</tr>
</tbody>
</table>

![Diagram showing suggested passing moments for the night schedule](image)
Conclusions

As seen the Delft experimental system for the bus monitoring has some limits, such as:
- detection content is limited to few indicators
- detection is discontinuous
- detectors are not located at bus stops
- detectors are chosen among detectors used for bus priority at intersection, therefore their availability along a bus line depends on the availability of dynamically controlled intersections

Despite the bus monitoring system limits, important uses have been made with the available detections. A custom software package has been developed for detection processing and analysis. This software allows to select reliable detections and to extract several useful indicators for the public transport performance as well as for the control of detector operation.

The software usability in Delft
Significant results have been found and illustrated for line 64. This line in fact shows a good enough availability of detectors. Useful results can be easily extracted by means of this software for some of the other lines in Delft. The consequent need to increase the number of detectors, as well as the Municipality will to do so, leads us to envision the subject for another applied research: "Study for an optimal choice of bus monitoring detectors among the available detectors in use for bus priority".

The software usability in other projects.
In the light of the promising results obtained, an extension of the research is going to be realized soon. Detections already processed by the implemented software will be used for the real-time prediction of the arrival time of buses at stops. Furthermore in November 1999 a conference is going to be held on the Delft bus monitoring system and Tritapt application to the system. Parties involved will be:

- Transportation Research Laboratory of the DELFT UNIVERSITY OF TECHNOLOGY and the Traffic Research Section of the DELFT MUNICIPALITY as the developers of the bus monitoring system.
- Municipalities of DEN HAAG and ZOETERMEER as potential bus monitoring network developers.
- CONNEXXION bus company whose buses have been detected and whose databases have been accessed. But also for another reason: this company operates in Den Haag and Zoetermeer.
- HTM bus and tram company whose tram line number 1 has a terminal in Delft and is well detected by the monitoring system. But also because this company too operates in the city of Den Haag (and others in the Zuid Holland).

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References

[1] For maps, explanations on the Delft bus monitoring system and the Detection Database refer to:
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[2] For the electronic time-table refer to the new bus company in Delft:
Connexxion Company. http://www.connexxion.nl

[3] For the Tritap software and its application to Eindhoven refer to:
Theo Muller
E-Mail: Th.H.J.Muller@ct.tudelft.nl
Phone: +1 617 373 3990
or refer to: Ir. Peter Knoppers (see Contact persons)
or visit the Internet site: http://www.trail.tudelft.nl/verkeerskunde look for Staff, than Management,
Peter Knoppers, More...,Work at the Civil Engineering department and finally “TRITAPT web
pages”.

[4] For more information about the software package described in paragraph 3.3 contact:
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