Co-ordinated traffic control in freeway corridors

S.P. Hoogendoorn / P.H.L. Bovy / N.J. van der Zijpp

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CO-ORDINATED TRAFFIC CONTROL IN FREEWAY CORRIDORS

a proposed evaluation approach

Authors:
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Date:
26 May, 1997
PREFACE

In the course of the Telematics Applications Programme Transport of the European Commission Fourth Framework Research Programme much attention is devoted to evaluation and demonstration. This report is part of the DACCORD project TR1017, devoted to the development and application of co-ordinated traffic control in freeway corridors.

This report develops a methodology for the evaluation of the performance of co-ordinated control strategies and measures aimed at optimising traffic flows in freeway networks.

The evaluation methodology is developed by a research team from the Delft University of Technology, Faculty of Civil Engineering, with the aid of the participants in the DACCORD Research Consortium. Special thanks are due to Professor Joe Whittaker, member of the peer review team, for his valuable comments.

The DACCORD consortium:

HCG, CSST, INRETS, TUC, TNO-TPD, AINE, CWI, RWS-NH, TUD, ULANC, UNA, SIER, SRILOG, VP, AVE, CELCIUS, DRA, RWS-AVV, TECHN, TNO-INRO, ASM, MIZAR
TECHNICAL ABSTRACT

In this report, the evaluation plan for the Fourth Framework programme DACCORD\(^1\) is presented. An extensive methodology has been applied to prepare a systematic and comprehensive evaluation plan. The plan addresses all relevant impacts on the target-users and other stake-holders of the ATT-applications at the DACCORD sites at various levels of assessment. It contains among others an analysis of general and experimental assessment objectives, a specification of performance indicators enabling evaluation at distinct levels of assessment (i.e. technical level, user-acceptance, impact analysis, and socio-economic assessment), and a description of various tools for validation.

The plan has been developed to be site-independent to a large extent, thereby maximising the potential for cross-site comparison, by proposal of common verification and demonstration plans for the distinct sites. Additionally, the use of an evaluation methodology prescribed to all projects of the Fourth Framework, enables harmonisation of results from other European ATT-projects. Consequently, the DACCORD evaluation plan clearly exhibits so-called “European Added Value” both through maximised cross-site as well as cross-programme comparison potential.

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\(^1\) DACCORD = Development and Application of Co-ordinated Control of Corridors
SUMMARY

Any decision on development or implementation of Transport Telematics applications should be made based on sound knowledge of the impacts and performance of these applications (for example, changes in travel time, effective capacity, diverted traffic proportions, effectiveness of the control measures, or the ratio between costs and benefits). The main objective of the evaluation is to objectively assess:

1. the impact of the developed traffic control technologies and system elements on the key-users;
2. the extent to which the research objectives have been reached.

The evaluation plan aims to maximise the potential for comparative analysis, both between sites, and between other Transport Telematics research programmes. Also, the plan has been prepared considering the objective that the assessment and validation activities are performed in harmony with evaluation of other Advanced Transport Telematics (ATT-) applications programmes, enabling the exchange of results from evaluation of other European ATT-programmes.

The evaluation plan answers two questions: "Which impacts following from the implementation of the traffic control tools and applications will be assessed?", and "How can these impacts be determined from simulated or real-life measurements?"

With respect to the first question, the evaluation plan is more than a blunt enumeration of performance indicators describing the quantifiable effects and impacts of the applications; the evaluation plan is comprehensive, in the sense that the following points are taken into account:

1. the relevant dependencies between policy makers, network operators, system operators, road-users, and infrastructure providers;
2. the general objectives and 'personal' preferences of the main users affected by the applications;
3. the assessment categories at the different levels of assessment (technical functioning of the application, acceptance of users, impacts, or socio-economical evaluation)

The need for both cross-comparison between tools and applications (how does the improvement in the frequency and severity of congestion due to mainline metering compare to the improvement due to dynamic route guidance?), and cross-comparison of tools and applications between sites (how does the integrated ATT-system in Amsterdam compare to the integrated ATT-systems in Paris or Italy?), requires the utilisation of a common evaluation plan for both tools and applications, and for each of the experimental sites.

To this end, the guidelines provided by the CONVERGE taskforce are adhered to a large extent. On the one hand, application of this methodology provides a good foundation for preparing evaluation plans for general transportation telematics projects. On the other hand, following these guidelines ensures maximisation of comparison potential between ATT-programmes of the Fourth Framework.

Regarding the second question, the evaluation plan provides guidelines for the design of field trials at the test-sites, by description of data-requirements, necessary for computation and analysis of the various proposed performance indicators either
by means of simulation studies (verification), or real-life field trials (verification and demonstration). Results from verification and demonstration are used to assess to what extent the project objectives have been satisfied.
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1. **INTRODUCTION**

1.1. **Definition and objectives of evaluation**

A key step in the development and implementation process of any application in the field of Advanced Transport Telematics (ATT) is *assessment* of results arising from its real-life implementation: any decision on the *development* or *implementation* of Transport Telematics applications should be made based on sound knowledge of the *impacts* and *performance* of the application (e.g. changes in travel time, effective capacity, diverted traffic, effectively of the control measures, or the ratio between costs and benefits). In this section, the general objective of *evaluation* with respect to the DACCORD programme is discussed. Here, the definition of *evaluation* proposed in [2] is given by:

**Evaluation**

"the process of determining the value of an application in comparison to alternative applications and/or to a "base case", and deriving recommendations for decision makers based on identified requirements on and analysed results of related experiments."

In order to perform an evaluation study, both *assessment* and *validation* are key steps to be taken. In this respect, the following definition of 'assessment' proposed in [2] is adhered:

**Assessment**

"the process of determining the performance and/or impacts of an application, usually in comparison to a reference case (existing situation or alternative application), and usually including an experimental process based on real-life or other trials, often involving users"

**Validation**

"the process of testing how an application performs with respect to the assessment objectives"

Validation is usually considered as an *extension* to the assessment process:

The main objectives of the evaluation of the applications to be implemented in the DACCORD project are:

*to objectively evaluate:*

1. the impact of the developed technologies and system elements on the distinguished target groups;
2. the extent to which the project objectives have been reached.

1.2. **The DACCORD Framework**

The DACCORD Transportation Telematics Programme is part of the Transport Sector of the Telematics Application Research and Development Programme, managed by the European Commission — DGXIII. The DACCORD Programme is concerned with the development and application of co-ordinated traffic control of freeway corridors and networks.

1.2.1. **Background**

Design and application of co-ordinated and integrated traffic control tools within the DACCORD project can be seen as a continuation from previous research done in DRIVE I and DRIVE II projects. For the practical application-part, the
DACCORD project builds upon results of the CHRISTIANE, GERDIEN, DYNA (integrated and co-ordinated modelling and forecasting tools) and EUROCOR (integrated and co-ordinated modelling tools and implementation concepts) projects.

1.2.2. The DACCORD Objectives
The overall objective of the DACCORD project is to design, implement and evaluate an advanced dynamic traffic management system for integrated (i.e. network-wide) and co-ordinated (co-operative and simultaneous consideration of diverse traffic control measures) control of corridors of interurban motorways. Additionally, an objective is to further develop an open system architecture for interurban traffic management.

More specific main objectives of the DACCORD project are summarised below:

- evaluation of on-line short-term forecasting techniques of flows and speeds in order to predict travel times, by means of comparison between predicted and observed values, using different prediction methods;
- assessment of practical results from motorway-to-motorway control, both in terms of operational methodologies and in terms of impacts on traffic flow;
- development of methodologies for integrated and co-ordinated control, including its effects on network-wide traffic flows, speeds and travel times;
- open system architecture: providing a framework for the integration of existing and future dynamic traffic management applications, improving inter-operability, and contributing towards an open European market for products and services, by improving competitiveness of the European industry, and the efficiency of services of public interest.

1.2.3. The DACCORD Measures
The DACCORD project addresses the needs and requirements of the road-authorities and traffic operators responsible for parts of the European motorway network to improve the efficiency and safety of the collective of end-users on the network. In order to reach these objectives, state-of-the-art techniques in the area of traffic management and control are employed.

1.2.3.1. Synergetic Effects
Within the duration of the DACCORD project, Dynamic Traffic Management (DTM) measures are designed and implemented at the distinct test-sites. These measures are either new, or have already been introduced (gradually) in either the DACCORD test-sites, or test-sites of other ATT projects. Depending on the distinct sites observed, they include ramp-metering, motorway-to-motorway control, variable message signs, individual route guidance, and variable speed limitations.

Since these measures may have partially dependent, or even conflicting objectives, it is envisaged that regulating these 'synergetic effects' by means of integrated and co-ordinated control is necessary for the maximisation of overall control efficiency with regard to the control objectives. Therefore, within the DACCORD project, generic, co-ordinated control tools for interurban motorway traffic networks will be developed and implemented at the distinct verification and demonstration sites.
1.2.4. **DACCORD Test-Sites**

In order to validate the measures developed and proposed in the DACCORD projects will be verified and demonstrated in three major test-sites:

- the Amsterdam network, part of the EuroDelta initiative;
- the Paris network, including the ringroad and the surrounding urban network;
- the Padua-Venice motorway, part of the Pitagora initiative.

The traffic operators (the *users* of the applications to be implemented) are all participants of the consortium. They are involved in all phases of the project, thereby emphasising *tangible* and *applicable* results, rather than ongoing research.

1.2.5. **Support Programmes**

For both DACCORD and other Advanced Transportation Telematics (ATT) programmes of the Fourth Framework, the European Commission has initiated support-programmes (e.g. CORD, CONVERGE, ANIMATE, and CODE). Main objectives of these programmes are to maximise the potential for comparative analysis between distinct ATT programmes of the Fourth Framework, and to ensure a high degree of quality. During the completion of this report, support of the following programmes was (explicitly) utilised:

**CORD [project v2056]:** the CORD project provides a commonly agreed “function list” (or more precisely, functions and sub-functions) for projects in the Fourth Framework Programme on (Road) Transport Telematics Applications. Aim of the list is to provide a more efficient exchange of information between interested parties, projects and institutions. An additional aim is to furnish the basis for a wide range of studies and activities, including architecture development, definition of technologies and systems catering for the envisaged range of services, institutional and legal analysis, and market definition and analysis.

**ANIMATE [project TR1102]:** the ANIMATE support programme provides administrative and technical support to the EC and projects. ANIMATE provides guidelines for among others the format of the reports. All reports will go through ANIMATE before they reach the EC.

**CONVERGE [project TR1101]:** the CONVERGE programme provides in-depth support for specific issues. With respect to evaluation, the most important sub-project is CONVERGE—Validation Quality. This support-project provides both guidelines for the determination of an evaluation plan, and feedback of these evaluation plans. Additionally, the CONVERGE — VQ -team provides the European Commission with detailed reviews of the DACCORD evaluation plans. Documents [1] and [2] result from the CONVERGE—Validation Quality sub-project, and provide a framework for the assessment of Transport Telematics Applications.

**CODE [project TR1103]:** the CODE project provides guidelines for, among others, the assessment of traffic safety (traffic safety group). Of the CODE projects, results from the HOPES horizontal programme were explicitly used (see [12]).
1.3. Motivation for the Use of an Evaluation Methodology

In general, an evaluation plan should answer three basic questions: First, “Which impacts following from the implementation of the ATT-tools and applications need to be assessed?”. The second question is “How can these impacts be determined from simulated or real-life measurements?”. Finally, “How can we determine, of the basis of measured impacts, the overall value, benefits and success of the ATT-tools and applications?”. With respect to the first question, preparing an evaluation plan should be more than a blunt enumeration of performance indicators describing the quantifiable effects and impacts of the transportation telematics application. Such an approach would most surely result in an ‘incomplete’ validation plan, implying that not all impacts caused by the implementation of the traffic control tools, and applications, are measured and analysed.

A comprehensive evaluation plan should at least take the following points of interest into consideration:

1. the relevant dependencies between policy makers, network operators, system operators, road-users, and infrastructure providers;
2. the general objectives and ‘personal’ preferences of the key user-groups affected by the application;
3. the assessment categories at the different levels of assessment (technical functioning of the application, acceptance of users, impacts)

The need for both cross-comparison between tools and applications (how does the improvement in the frequency and severity of congestion due to mainline metering compare to the improvement due to dynamic route guidance?), and cross-comparison of tools and applications between sites (how does the integrated ATT-system in Amsterdam compare to the integrated ATT-systems in Paris or Italy?), requires the utilisation of a common evaluation plan for both tools and applications, and for each of the DACCORD sites.

Consequently, to provide the means to assess the impacts and additional effects on all target users and other stake-holders of interest, as well as to maximise the effectiveness and benefits of a Transport Telematics programme, projects should adopt consistent assessment and validation methods.

In this respect, the evaluation plan described in this report adheres to the CONVERGE methodology for the preparation of evaluation plans, proposed in [2] to a great extent. Following the general guidelines proposed by this methodology, does not only enable cross-comparison between the different sites involved in the DACCORD project, but also provide the means to consistently formulate a comprehensive evaluation plan, addressing the most relevant impacts of DACCORD applications.

1.4. Summary of the Evaluation Methodology

The assessment process starts with the analysis and the description of the user-needs and preferences. Subsequently, the applications to be assessed are described.
Description of the applications enables attribution of (1) the extent of user-acceptance, (2) the benefits to target-users, decision makers and other stakeholders, and (3) the expected impacts on key users of the applications to each separate application.

The assessment objectives are specified, based on the needs and preferences of key decision makers and other stakeholders. Together with the characteristics of alternative systems and available resources, these determine the assessment categories to be invoked to meet the objectives of the Advanced Transportation Telematics (ATT-) Programme. After analysis of the expected impacts, a detailed plan for validation is determined.

In the final validation plan, performance indicators are identified for each of the experimental assessment objectives. The performance indicators implicitly reflect additional restrictions due to limited resources, and cross-site comparability of the results. Subsequently, tools for assessment of the performance indicators at the relevant levels of assessment are presented. Additionally, an ‘overall definition of success’ is defined.

1.5. Outline of Final Evaluation Plan

The first chapter of this report concern general issues of the DACCORD project, both with respect to the project as a whole, and more specific to the evaluation phase. The remainder of the final evaluation plan is divided into two parts: part A, and part B.

Part A can be read separately from part B. It outlines how we have determined which impacts to be assessed. Part B can be read separately from part A, although at same points reference is made to part A. It addresses how we will measure the different expected impacts identified in part A.

Part A describes the evaluation methodology, and applies it to derive the general evaluation objectives. To this end, after identification of the relevant users and key-decision makers, together with their needs and preferences (chapter 2), the relevant DACCORD applications are described at a site-independent level (chapter 3), maximising cross-site comparison potential. Both the design objectives of the applications, and the general assessment objectives are identified for all DACCORD applications (chapters 4). Additionally, applicable categories of assessment are introduced (section 4.5). To conclude the first part of the final evaluation plan, the results from pre-assessment are presented (section 4.6).

In part B, the validation plan is presented. In the first chapter, assessment objectives, which can be analysed 'directly' by simulation- and field-studies, are presented. In chapter 6 (the measurement plan) describes the performance indicators — both for the assessment of individual and integrated ATT-applications — relevant for validation in DACCORD. Additionally, data requirements are identified. In chapters 7, 8, 9 and 10, the experimental set-up for assessment at respectively the technical, user-acceptance, impact, and socio-economical levels, are described. In these chapters, tools for validation are proposed, the experimental assessment objectives are combined with specific performance indicators, and an ‘overall definition of success’ with respect to these assessment objectives is proposed.

In Figure 1, the subdivision of the report is indicated, both in terms of the two parts A, and B, as well as the different chapters of the report.
PART A

CHAPTER 3: Generic Description of DACCORD Applications
appl. 1 appl. 2 appl. N
application functions, interdependencies, and objectives

CHAPTER 4: Towards Assessment Objectives
ass. obj. 1 ass. obj. 2 ass. obj. P
application independent assessment objectives

CHAPTER 4.6: Pre-Assessment: Anticipated Impacts for each Application
appl. n impact
(target user-group ++/+/0/-/---)

PART B

CHAPTER 5: Preparation of the Validation Plan
appl. n general ass. objectives
categories of assessment objectives

CHAPTER 5-10: Experimental Set-Up for Technical Assessment, User-Acceptance, Impact- and Socio-Economic Assessment
tools for validation
overall definition of success
experimental set-up

Figure 1: Outline of the Final Evaluation Plan
PART A:

Towards General Assessment
Objectives
a proposed evaluation approach
2. **DACCORD USERS AND DECISION-MAKERS**

### 2.1. Introduction

One of the main tests when designing any Transportation Telematics system is to assess how the applications can be designed to meet users' needs most efficiently. In general, the main objective of evaluation is to determine to what extent the designed application fulfils these user-needs. Consequently, detailed examination of the preferences and requirements of the users of the application is invaluable for any Advanced Transportation Telematics Programme.

For the DACCORD project, this analysis has been performed in the first phase: determination of user-needs for dynamic traffic management. In [8], the following definition of a user is proposed:

> Users "the humans on whose behalf the system is developed"

The next step, is the identification of the so-called decision makers, which are present at the distinct sites. The following definition of a decision maker is adhered to in the sequel of this report:

> Decision Makers "those responsible for the production, the introduction, and/or the implementation of the ATT application, e.g. governmental agencies (local, national, European), or system providers"

Decision makers have goals and objectives and have the means to achieve these.

Most projects take the needs and requirements of several users into account. For DACCORD the relevant EC, national and city authorities must be taken into account. Within the DACCORD-framework, the following are relevant examples of these needs and requirements:

- the *European objective* of improving system interoperability or of promoting the European transport telematics industry section;
- the *national objective* of improving traffic safety and transport efficiency;
- the *local need* of improving traffic management in a network.

The decision makers which are identified should be relevant with respect to the *scope of evaluation* of the distinct ATT-applications being assessed.

This chapter discusses the needs and requirements of both the users and the decision-makers. The different users are identified first. Following this identification, the needs of these users, resulting from thorough user-need assessment which has been carried out in the first phase of the DACCORD project, are presented. Modifications and additions to these results, both in terms of the different user-classes identified, and their needs and preferences, are proposed for evaluation-specific purposes. Finally, the decision-makers are identified, and their needs and requirements are presented as well.
2.2. Identified Users in DACCORD

In [8], users are categorised on the basis of their common characteristics. The characteristics identified for this purpose are perspective, that is either long-term, medium-term, short-term, and very short-term, and area-size, that is large (national), network-size (regional), corridor-size (local), and journey-size (route between origin and destination).

The distinction made in this report is generic, i.e. site-independent, enabling a high level of integration at site-level. The following user-classes resulted from user-needs analysis (see [8]):

1. **policy makers**: i.e. public authorities (either local regional, national, or international). The objectives of the policy maker have a long term perspective. The general aim is to provide a cost-effective, safe and efficient transportation system. The main policy maker being identified within the DACCORD project is the European Commission — DGXIII. Site specific policy makers are the Ministry of Transport, Regional Directorate North-Holland (Amsterdam test-site), the Ministry of Equipment, Lodging, Transport and Tourism (Paris test-site), and the Regional Authorities, City Councils of the cities close to the Brescia-Venezia Motorway (Padua-Venice test-site).

2. **network operators**: that is the managers of the network. Their main objective, having a medium term perspective, is to translate the policies into practical plans and study programmes, and thus provide a cost-effective, safe and efficient road network system. In effect, in the DACCORD project, the identified network operators are the Ministry of Transport, Department North-Holland (RWS-NH), Rijkswaterstaat Transport Research Centre (RWS-AVV), the Service Interdepartmental d’Exploitation Routière (SIER), the Ville de Paris (VP), the Autostrade Italia Nord-Est (AINE), and the city of Brescia (ASM).

3. **system operators**: i.e. the crew managing the road traffic on a day-to-day basis at the distinct sites. Their objectives are the day-to-day running of a safe and efficient network, using the facilities provided by the network operators.

4. **drivers**: the individual road-users affected by the application. This group can in itself be divided into different categories. For evaluation purposes, it is proposed to categorise these end-users with respect to their origin and destination of the trips. In this respect, distinction should be made between urban network, or interurban network originated or destined traffic. It is envisaged that the applications will affect the user-groups defined herein in a significantly distinctive manner.

However, due to the extent of the evaluation, the user-groups and their user-needs mentioned earlier, do not cover all relevant requirements regarding the DACCORD ATT-applications. For example, the impact of ATT-applications on the environment (noise-production, air-pollution, etc.) is not taken into account. Therefore, an additional user-group is identified:

5. **non-users or victims**: the non-users or victims of the applications implemented in the course of the DACCORD project, comprise among other the residents living in the vicinity of a road, and the society as a whole. Although in general not directly using the facilities, the victims can either suffer or benefit from the implementation of ATT-applications.
2.3. Determination of User-Needs

All users identified have objectives, and means to reach those objectives. The objectives of a user can be to provide an 'optimal' service to another user. The means to reach the users' objectives range from controlling day-to-day traffic flow using dynamic traffic management measures, (short-term), introduction of dynamic traffic management facilities (medium-term), or the allocation of resources to research and development or drawing up general traffic plans (long-term).

2.3.1. Review of Identified Users, their Needs and Requirements in DACCORD

The following table summarises the results of the analysis with respect to user-requirements for evaluation purposes.
<table>
<thead>
<tr>
<th>Identified Users (DACCORD independent)</th>
<th>Identified Users (DACCORD specific)</th>
<th>Perspective and Area-Size</th>
<th>General Needs and Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy Makers</td>
<td>General: European Commission</td>
<td>long term (years, decades)</td>
<td>enforcement of co-ordinated control to the extend that it positively influences traffic conditions</td>
</tr>
<tr>
<td></td>
<td>Site Specific: Amsterdam:</td>
<td>large area (regional)</td>
<td>serious considerations for the opinion of directly affected users</td>
</tr>
<tr>
<td></td>
<td>• Ministry of Transport, Regional Directorate North-Holland, policy section</td>
<td></td>
<td>suitable concertation mechanisms for early resolution of regional or administrative conflicts</td>
</tr>
<tr>
<td></td>
<td>• Ministry of Equipment, Lodging, Transport and Tourism</td>
<td></td>
<td>insight in the European Added Value of the DACCORD project (see notes below), regarding:</td>
</tr>
<tr>
<td></td>
<td>• DREIF (SIER)</td>
<td></td>
<td>○ extendibility</td>
</tr>
<tr>
<td></td>
<td>• Ville de Paris</td>
<td></td>
<td>○ flexibility</td>
</tr>
<tr>
<td></td>
<td>Padua-Venice:</td>
<td></td>
<td>○ transferability</td>
</tr>
<tr>
<td></td>
<td>• Regional Authorities, City Councils of the cities close to the Brescia-Venezia Motorway</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network Operators</td>
<td>Amsterdam:</td>
<td>medium term (months, years)</td>
<td>knowledge regarding probable impact of candidate control measures (results of assessment, verification, and demonstration of integrated and co-ordinated control systems)</td>
</tr>
<tr>
<td></td>
<td>• Regional Directorates North-Holland (operational sections)</td>
<td>network size area (regional)</td>
<td>insight in various technical and organisational aspects of control measures, such as:</td>
</tr>
<tr>
<td></td>
<td>Paris:</td>
<td></td>
<td>○ maintenance needs</td>
</tr>
<tr>
<td></td>
<td>• the Direction de la circulation Routière department</td>
<td></td>
<td>○ reliability and vulnerability of control installations</td>
</tr>
<tr>
<td></td>
<td>Padua-Venice:</td>
<td></td>
<td>○ system architecture</td>
</tr>
<tr>
<td></td>
<td>• Administrative employees and managers of the AINE and ASM companies</td>
<td></td>
<td>○ qualification of operating staff</td>
</tr>
<tr>
<td>System Operators</td>
<td>Amsterdam:</td>
<td>short term (days)</td>
<td>streamlining operations and minimizing mutual interference in an automatic, reliable and efficient way</td>
</tr>
<tr>
<td></td>
<td>• Operators at Traffic Control Centre</td>
<td>corridor-size area (local)</td>
<td>harmonisation of pursued control objectives</td>
</tr>
<tr>
<td></td>
<td>Paris:</td>
<td></td>
<td>higher efficiency in meeting control objectives</td>
</tr>
<tr>
<td></td>
<td>• SIER and Ville de Paris system operators</td>
<td></td>
<td>ergonomically efficient and flexible Human-Machine Interface, enabling direct intervention whenever necessary</td>
</tr>
<tr>
<td></td>
<td>Padua-Venice:</td>
<td></td>
<td>determination of precise set of rules regulating conditions for operator intervention</td>
</tr>
<tr>
<td></td>
<td>• Operators of the Traffic Control Centre</td>
<td></td>
<td>minimization of violations or other kinds of incorrect behaviour of drivers</td>
</tr>
<tr>
<td>Drivers</td>
<td>• Car drivers</td>
<td>very short-term (a moment)</td>
<td>individual efficiency (small travel times), and safety</td>
</tr>
<tr>
<td></td>
<td>• Car passengers</td>
<td>journey-size (route between origin and destination)</td>
<td>instruction concerning necessity of DTM applications</td>
</tr>
<tr>
<td></td>
<td>• Bus and truck drivers</td>
<td></td>
<td>information enabling optimization of individual route and lowering personal stress</td>
</tr>
<tr>
<td></td>
<td>• Bus and truck companies</td>
<td></td>
<td>improving environmental conditions (noise- and pollution level)</td>
</tr>
<tr>
<td>Victims</td>
<td>• Residents living alongside freeway</td>
<td>very short-term (a moment)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Workers in offices</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Identified Users and User-Needs
2.3.2. Some Comments with Respect to the Policy Maker European Commission

Although not addressed in the user-needs study, the policy maker the European Commission has a prime interest in the so-called European Added Value (EAV). Basically, the EAV of both the developed DACCORD methodologies and ATT-applications and the evaluation phase itself should explicitly account for this user-need.

2.3.2.1. European Added Value and the DACCORD Applications

For the DACCORD applications, the EAV implies the development and implementation of ATT-applications which are both flexible\(^2\), and extendible\(^3\). Moreover, the transferability or applicability of methodologies to a wide range of (European) sites, regardless of variations in topology, geometry, and traffic characteristics, is an important issue as well, with respect to the European Added Value. Clearly, whenever these issues are within the extent of evaluation in DACCORD, they should be addressed in the evaluation phase. Note that the extendibility and the flexibility of the system are also identified as being needs of the network operators.

2.3.2.2. European Added Value and DACCORD Evaluation

To address the EAV-issue in DACCORD Evaluation is a different issue. Designing in EAV implies two requirements:

1. to clearly show the benefits of the developed and implemented ATT-applications, maximising cross-project comparison, to allow the real “customers” to compare the different ATT-applications

2. to maximise the integration at site-level within the evaluation process, for example by identifying common assessment objectives, indicators of performance, common measurement-plans, etc. Basically, the rule of thumb is whenever common applications at common sites are implemented, a common evaluation plan should be employed, hence maximising the potential for cross-site comparison.

2.4. Decision Makers, their Needs and Preferences

2.4.1. Decision Makers in DACCORD

In the DACCORD project, the decision makers among others consist of the local and European agencies responsible for the implementation of the ATT application. Thus, the following decision makers are identified in DACCORD:

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\(^2\)Extendibility of the advanced dynamic traffic management system denotes the potential for extension of the control system by additional parts of the network, or additional ATT-applications. Thus, the extendibility of the system reaches beyond that of DTM-evaluation, towards the architectural level.

\(^3\)The flexibility of a system determines the possibility of adjusting application objectives and constraints after implementation of the applications. For example, the modification of certain control objectives, due to heightened environmental interest, may cause the control objective to become ‘minimise fuel consumption’, instead of ‘minimise travel-time’.
• the European Commission (EC);
• the regional traffic managing organisations (network operators), i.e.:
  - the Ministry of Transport, Department North-Holland (RWS-NH), and the Rijkswaterstaat Transportation Research Centre (RWS-AVV) (Amsterdam test-site);
  - the Service Interdépartemental d'Exploitation Routière (SIER), and the Ville de Paris (VP) (Paris test-site);
  - the Autostrade Italia Nord-Est (AINE), and the city of Brescia (ASM) (Padua/Venice test-site);
The objectives of the network operators are in general the provision of a cost-effective, safe and efficient road system. Moreover, the interests of the system-operators are directly taken into consideration. Consequently, the user-needs of the end-users, that is the drivers, of the application are taken into account indirectly as well.

For successful implementation, the needs and preferences of the decision makers reflect among others the needs of users whose interest is taken into account by specific decision makers (for DACCORD these consists of the system, the network managers, and the road-users).
3. **GENERIC DESCRIPTION DACCORD APPLICATIONS**

### 3.1. Introduction

A precondition for an effective assessment and validation plan must be a clear and concise description of the key characteristics of the ATT application to be evaluated.

In DACCORD, evaluation is carried out for three different verification and demonstration sites, in different countries, where various (and sometimes distinct) transport telematics applications are tested. In line with the recommendations given by the CONVERGE methodology (see [1]), each DACCORD application is described, where the following aspects are identified:

- site identifier;
- application identifier;
- general system objectives defined when designing and developing the application;
- relevant CORD functions and sub-functions (see [6]);

Each isolated application (stand alone application, which has its own means for the collection, storage, and processing of data, computation of control settings, actuation, etc.), and each integrated application (applications having shared means for collection, storage, and processing of data, computation of control settings, actuation, message dissemination, etc.) should be described precisely for every test-site.

#### 3.1.1. Notation and Definitions

Before continuing, recall the definition of an application from [11]:

**Application**

"a telematics system or service as installed and operating in a real-life environment"

In the ensuing section, the following terminology is used:

**Section**

"homogeneous part of the road-network between intersections (merges, diverges, or other localised areas). No deviation from or entry to a section is possible via part of the public road network"

**Intersection or Point**

"part of the road-network where traffic streams split or merge"

**Network**

"part of the road-network for which one unit of traffic management is responsible for direct management activities"

### 3.2. CORD Functions and Subfunctions

Additionally, the CORD Functions and Subfunctions are depicted for each application described (see [2]). These definitions and classifications are based on a
three-layer hierarchy (introduced by DRIVE I/SEFCO [7]). This hierarchy comprises Areas, Functions and Subfunctions.

The areas are sets of functions related by the purpose of the services provided. The areas applicable in DACCORD comprise Demand Management (A2), Traffic Management (A3), Parking Management (A4), Public Transport Management (A5), Traffic Information (A6), and the Internal Services (A10).

In [6] it is proposed that areas are merely used as a tool to structure the function list, as real system implementations must normally be build by using functions and sub-functions from several areas. The functions are groupings of two or several complementary or alternative sub-functions. The sub-functions are the single elements of a function.

In section 3.3, the distinct applications due for evaluation in DACCORD are listed. In order to provide an evaluation plan which is generic for all sites, and hence provides for a high level of cross-site comparison potential, generic terms have been used to indicate the distinct applications at the distinct sites. These generic terms indicate applications which, although varying in the way they are implemented (their functional 'specification'), are functionally the (see [13]).

In section 3.3, results from relating the ATT-applications identified in DACCORD to the different CORD areas, functions, and sub-functions, are given.

Applications in DACCORD cover three areas of the CORD functions and sub-functions, that is area A3 (traffic management), area A6 (traffic information), and area A10 (internal services). In the following sections, these areas are described in more detail. Additionally, the different functions and sub-functions relevant for DACCORD ATT-applications are presented, and clarified if necessary.

**A3: Traffic Management.** The traffic management area covers ATT-applications for traffic control in conformity with demand management principles for both urban and inter-urban traffic networks. The following functions and sub-functions within the traffic management area are applicable to DACCORD applications:

**F3.1:** Section Traffic Control

- **SF3.1.1:** Section State Monitoring
- **SF3.1.3:** Section Control Computation
- **SF3.1.4:** Section Control Actuation

**F3.3:** Network Traffic Control

- **SF3.3.1:** Network State Surveillance
- **SF3.3.2:** OD Computation and Route Assignment Estimation
- **SF3.3.3:** Demand Prediction
- **SF3.3.4:** Traffic Prediction
- **SF3.3.5:** Network Control Computation

**F3.4:** Localised Area Control

- **SF3.4.2:** Ramp Control
- **SF3.4.6:** Mainline Metering Control*

---

* Originally, mainline metering is not a function identified within the CORD function and sub-function framework, and is identified by the evaluation manager for DACCORD-applications only.
A6: Traffic Information. The traffic information consist of applications providing dynamic traffic and traffic-related information to drivers using either "collective" means (e.g. Variable Message Signs), or individual in-vehicle terminals. Information provision is in general characterised by shorter temporal and geographic spans, i.e. provided to the road-users in the course of a trip, and generally being specific and relevant to the actual driving task and the location of the vehicle. The goal of traffic information is in general to influence route-choices. The following functions and sub-functions within the traffic information area are applicable to DACCORD applications:

F6.2: Navigation
- SF6.2.4: Collective (network) Route Computation
- SF6.2.6: Collective Journey Time Computation

F6.3: Dynamic Route Information
- SF6.3.5: Traffic Conditions
- SF6.3.9: Routes
- SF6.3.10: Section Travel Times

A10: Internal Services. Finally, the internal services is a set of functions performed inside the system, ranging from long- and medium-term policy making, to the measuring and detection of traffic and environment describing data.

F10.2: Detection/ Measuring
- SF10.2.9: Vehicle Detection (SF3.1.1)

F10.3: Modelling
- SF10.3.1: Demand Prediction (SF3.3.3)
- SF10.3.2: Traffic Prediction (SF3.3.4)

F10.5: Information Interchanges
- SF10.5.1: Information Interchange Management
- SF10.5.2: Continuous Information Interchange

F10.6: Message Selection
- SF10.6.1: VMS Message Selection

For each ATT-application described in the following sections, the relevant CORD functions and sub-functions are given.

3.3. Site Independent Tools and Applications

This section presents an overview of those ATT-tools and applications, relevant for evaluation within the DACCORD project. To ensure maximisation comparison potential, the DACCORD tools and applications are described by the functionality, instead of their respective site specific implementation. This issue is addressed more elaborately in the remainder of this section.

3.3.1. Functional Architecture and DACCORD Tools and Applications

For the description of the ATT-tools and applications in DACCORD are described in terms of their functional behaviour instead of their implementation-specific
characteristics. Such a description of tools and applications is beneficial due to the following facts:

1. a functional framework enabling classification of DACCORD ATT-applications in terms of functioning instead of specific implementation at the separate sites facilitates comparison across sites, thereby enhancing the European Added Value-potential of evaluation in DACCORD.

2. the interdependencies of applications can be more easily depicted. This can greatly facilitate the explanation phase of the evaluation process. For example, deficient functioning of an application providing input (e.g. data cleaning systems providing input for estimation procedures) may result in seemingly poor functioning of application receiving poor inputs. Therefore, knowledge of these interdependencies is essential for valuable evaluation.

The DACCORD tools and applications are organised by their functionality, using different levels of abstraction. The highest level of abstraction is the functional architecture of general advanced dynamic traffic management systems. The following definition of a functional architecture is taken from [13]:

The Functional Architecture addresses the functional behaviour of the Central Traffic Management Systems. In other words, it shows how the systems operate in terms of the main independent processes and their logical flow of information between those processes. By its definition, a Functional Architecture distinguishes itself from the design and realisation domains that describe how the Central Traffic Management System will be implemented.

The lowest level of abstraction describes the functional specifications at test-site level (see [14]). However, since the separate DACCORD sites differ at the functional specifications-level, among others due to differences in implementation at the separate sites, this level of detail is unsuitable for cross-site evaluation purposes. Additionally, both cross-application and cross-project evaluation potential decreases when using a functional description which is too detailed. Therefore, the functional architecture level is chosen for description of the DACCORD ATT-applications for evaluation purposes.

3.3.1.1. The Functional Architecture: 'Behavioural Model'

In Figure 2, the functional decomposition depicting a site-independent overview of the functioning of DACCORD applications is presented. In this report, the functional decomposition consists of four stages:

1. collection of traffic data (e.g. inductive loop data, and actuator settings);
2. data qualification and reconstruction;
3. estimation and prediction of the traffic state and derived quantities (e.g. capacity of a bottleneck, queue lengths, turning fraction estimates);
4. determination of control settings, and actuation.

The DTM-systems considered in DACCORD in the different test-sites fit into this functional framework, and clearly exhibit all stages of the functional decomposition outlined in Figure 2. In this scheme, only the dependencies between the different ATT-applications required for evaluation are depicted.

5 Explaining deficient functioning of ATT-applications from validation results.
The functional architecture level can be called *generic*. In effect, a large range of DTM-applications—hence also the DTM-systems in DACCORD—can be described using the general functional architecture presented in Figure 2.

*TRAC: Traffic, Road, and Ambient Conditions

![Diagram](source:image_url)

*Figure 2: Functional Decomposition for DACCORD-Systems (Source: DACCORD Report 4.2: Functional Architecture)*
In the ensuing sections, the functions depicted in Figure 2 are decomposed into more detailed — but still generic — functional descriptions, until the description becomes too detailed for evaluation purposes.

**Data Collection:**

Applications involved:

1) induction loop systems

Relevant CORD functions:

- F3.1 (SF3.1.1)
- F10.2 (SF10.2.9)

Although data collection systems in DACCORD comprise both inductive loops and CCTV coverage of areas prone to incidents, the inductive loops generate the input for the data cleaning system. Additionally, log-files containing the actual control settings are foreseen as well.

**Data Cleaning:**

Applications involved:

1) data checking
2) data correction
3) data completion

Relevant CORD functions:

- F3.1 (SF3.1.1), F3.3 (SF3.3.1)

Basically, the data cleaning itself consists of three levels: data checking (identification of false or missing data), data correction (correction of false data), and data completion (reconstruction of missing data).
Estimation & Prediction:

The estimation for the DACCORD DTM-system basically consists of two levels. On the one hand a section-estimation provides for relatively simple estimation techniques for capacity, section performance, congestion detection, queue length, and instantaneous travel time. On the other hand, the traffic conditions of the entire traffic network can also be estimated, for example using Kalman filtering techniques. It should be noted that these network state estimation techniques can also be used to estimate e.g. capacity and queue-lengths, for example using a Schmidt-Kalman Filtering Approach, where these unknown parameters are estimated on-line, by augmenting the state of the system.

Section-Level State Estimation Tools:

Applications involved:
1) on-line capacity estimation
2) section-level congestion detection
3) static queue length estimation
4) travel time estimation

Relevant CORD functions:
- F3.3 (SF3.3.1)
- F6.2 (SF6.2.4, SF6.2.6), F6.3 (SF6.3.5, SF6.3.10)

Section-level estimation techniques are characterised by the way in which they are calculated. In principle, they can be derived from current and/or historic section-or station measurements. For example, the on-line TNO-capacity estimator (see [9]) can be calculated from section-flows only.
Figure 4 depicts the different applications to be evaluated in the DACCORD project, and their dependencies.

Network-State Estimation and Prediction Techniques:

Applications involved:

1) Statistical Traffic Model (STM): predictions (1-20 minutes) of flows, densities, and speeds;

2) Behavioural Traffic Model (BTM): predictions (10-60 minutes) of flows, densities, and speeds;

3) network-level queue length estimation and prediction;

4) travel times estimation and prediction.
Relevant CORD functions:

- F3.3 (SF3.3.1, SF3.3.2, SF3.3.3, SF3.3.4)
- F6.2 (SF6.2.4, SF6.2.6), F6.3 (SF6.3.5, SF6.3.9, SF6.3.10)
- F10.3 (SF10.3.1, SF10.3.2)

Network-state estimation and prediction tools use models and (historic) data in order to estimate and predict the state of the network, using e.g. the estimated section-level traffic states as inputs.

![Network-State Level Estimation Tools](image)

**Control:**

For the control part of the functional architecture, distinction in made between three different levels of control. This distinction is made based on the geometrics and size of the controlled area (either a point or localised area, a section or link, or a network). In effect, we distinguish between point control, section-traffic control, and network traffic control. Figure 6 depicts the different interdependencies between the different control levels.
Section Traffic Control:
Applications involved:
1) speed recommendation or regulation (e.g. variable speed limits)
2) lane use

Relevant CORD functions
- F3.1 (SF3.1.3, SF3.1.4)

Isolated section traffic control applications involve control application which can operate isolated from other applications present in the network, using section level traffic measurements. Characteristic for section traffic control (STC-) applications is the redundancy of network state estimation and prediction techniques. Hence, no extensive network modelling is needed in order to be able to provide for STC-control.

Point or 'Localised Area' Control:
Applications involved:
1) ramp-metering
2) motorway to motorway control

Relevant CORD functions:
- F3.1 (3.1.3, 3.1.4), F3.4 (SF3.4.2, SF3.4.6)

Isolated point control applications apply control measures to specific locations or areas in the network, requiring dedicated strategies due to their specific operational environment. On the one hand, as with section control-applications, isolated point control-applications do not require integration at any level. Usually, control generating algorithms require local data to calculate local area control settings. An example would be isolated ramp-metering, where local measurement on both the mainline, and on the on-ramp determine the control settings for the
ramp-metering installation, using a dedicated local control algorithm (e.g.
ALINEA, RWS-algorithm, or fuzzy logic, see [5]). In the DACCORD project,
isolated point control applications are integrated with both section control
applications, and network control applications, as will be described in the ensuing
sections.

**Network Traffic Control:**

**Applications involved:**

1) travel time display
2) queue length display
3) route guidance (variable direction signs)

**Relevant CORD functions:**

- F3.1 (3.1.3, 3.1.4), F3.3 (SF3.3.2, SF3.3.3, SF3.3.4, SF3.3.5), F3.4 (SF3.4.2,
  SF3.4.6)
- F6.2 (SF6.2.4, SF6.2.6), F6.3 (SF6.3.5, SF6.3.9, SF6.3.10)
- F10.3 (SF10.3.1, SF10.3.2), F10.6 (SF10.6.1)

For the network traffic control applications *travel time display, queue length display,*
and *route guidance,* availability of measurements of at least part of the network, and
section- or network- level estimates and predictions are required, to generate the
control settings of the network-control applications.

**Applications involved:**

3) integration of control measures (point control, section traffic control, and
VMS- or VDS-systems), and estimation and prediction tools (Operation
Support Systems, or Central Traffic Management Systems)

4) connection with other TCC's

**Relevant CORD functions:**

- F3.1 (3.1.3, 3.1.4), F3.3 (SF3.3.2, SF3.3.3, SF3.3.4, SF3.3.5), F3.4 (SF3.4.2,
  SF3.4.6)
- F6.2 (SF6.2.4, SF6.2.6), F6.3 (SF6.3.5, SF6.3.9, SF6.3.10)
- F10.3 (SF10.3.1, SF10.3.2), F10.5 (SF10.5.1, SF10.5.2, SF10.5.3), F10.6
  (SF10.6.1)

Combining point control applications, section traffic control applications, network
traffic control applications, and the various tools for estimation, and prediction, at
either section- or network-level, requires *integration* of tools and applications. The
level of integration is a key factor determining the performance of the resulting
integrated system. Moreover, connection of Traffic Control Centres requires some
level of integration.

### 3.4. Relation to Site-Specific Applications

In the following tables, for each of the test-sites, the different functions are related
to site-specific ATT-applications. For data collection, data cleaning, section-level
estimations, and network-level estimations and predictions, an outline of the
methods used is given in Table 2. For control, Table 3 indicates the separate
control applications due for implementation in a specific site, and whether it will be
implemented physically on the respective sites, or only in a simulated environment.

In the sequel of this report, these tables are used as reference for the connection of
the generic ATT-applications or functions described in the previous section, to site
specific ATT-applications and methodologies.

<table>
<thead>
<tr>
<th>Application</th>
<th>Site</th>
<th>Amsterdam</th>
<th>Paris</th>
<th>Padua-Venice</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. data collection</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>2. data cleaning</td>
<td>✓</td>
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<td></td>
<td>data checking</td>
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<td>data correction</td>
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<td></td>
<td>data completion</td>
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<tr>
<td>3. section-level estimation</td>
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<td></td>
<td>capacity estimation</td>
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<td>travel time estimation</td>
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<tr>
<td>4. network level estimation &amp; prediction</td>
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<td></td>
<td>Statistical Traffic Model (STM)</td>
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<td>Behavioural Traffic Model</td>
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<td>queue length estimation and prediction</td>
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<td>travel times estimation and prediction</td>
<td>✓</td>
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</tr>
</tbody>
</table>

'✓' = funded by DACCORD, '+' = funded outside DACCORD

Table 2: Reference table for generic Tools for Data Collection, Data Cleaning, Estimation, and Prediction
Table 3: Reference table for generic control applications

3.5. Generic Application Objectives

Advanced Transport Telematics applications are designed and implemented in order to achieve some sort of objective. Application objectives range from “improving the safety of the road-users” and “decreasing pollution level and fuel consumption” to “improving the efficient use of the infrastructure” and “providing decision-making assistance to road users”.

In general, an application objective reflects the needs and requirements of one or more user-groups. In this report, the identified user-groups are the policy makers, the network operators, the system operators at the Traffic Control Centres, the road-users, and the non-users or victims (society as a whole, or residents living in the vicinity of the infrastructural facility, see [8] and [11]).

The following application objectives are identified:
### Table 4: General Application Objectives and User-Dependencies

In the following tables, the general application objectives depicted in Table 4 are related to the different applications developed and implemented within DACCORD. Sometimes, a distinction is made between primary, and secondary objectives, in order to enable a more refined correspondence between the application and application objectives.

<table>
<thead>
<tr>
<th>Application</th>
<th>Appl. Obj.</th>
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<th>3</th>
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**Notes:**
- ++: primary objectives
- +: secondary objectives

*Table 5: Application Objectives for Data Collection, Cleaning and Estimation Functions*
### Table 6: Application Objectives for Control related Applications

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<th>Application</th>
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<td>speed recommendation/ regulation</td>
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<tr>
<td>integration of section- and point-control measures, and estimation and prediction tools; operator support (OSS-systems) or automated control determination (CTMS-systems)</td>
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<td>connection with other TCC's</td>
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</tbody>
</table>

3.6. Integration of Applications and Tools in DACCORD

In the following section, some features of integration at various levels are discussed. A number of basic features of an integrated traffic control system environment, distinguishing it from isolated ATT-applications are discussed. In this section, coordination of individual applications is defined as integration at the central control level.

3.6.1. Synergy

For the purpose of DACCORD evaluation we will define synergy by:

*Synergy* "the way the effects of the simultaneous utilisation of the ATT-tools and applications compare to the sum of separate effects"

In this respect, the overall performance of an integrated system is a result of the:

1. individual performance (effectiveness) of the isolated ATT-applications;
2. level of integration, and techniques used for integration of the distinct ATT-applications;
3. level of inter-application influences on the impacts due to the simultaneous implementation and operation of the ATT-tools and applications in DACCORD.

The evaluation process for the integrated DACCORD-systems aims to indicate both the overall performance of the systems, and the gain (or loss) in performance due to synergy of these subsystems. The latter goal is to be achieved by a before- and after analysis of the different indicators described in the previous chapters. In this case, the candidate
systems chosen are the candidate systems at different levels of integration (e.g. integration of tools and applications at the data-collection level, or integration at the central control level).

3.6.1.2. Integration

Generally speaking, a definition of integration in the present context is the following:

Integration “the use of common resources, e.g. equipment, data, models, storage media, or human skills.”

In the context of DACCORD the following levels of integration are relevant:

1. **no integration**: the no-integration level describes a transportation system where two or more isolated applications are (competitively) active, but do not share any common resources while operating;

2. **integration of data sources**: the integration of data-sources indicates the integration of data from e.g. inductive loops, CCTV, weather bureau's (short-term forecasts of weather conditions), information provided by the police, predictions of traffic conditions on neighbouring networks provided by remote traffic control centres. A requirement for this level of integration is the availability of these types of data in a same, or at least compatible format;

3. **integration at the data acquisition and data storage level**: common data is collected and stored by compatible facilities. Integration of data acquisition and storage ensures the running of the system on a common information base;

4. **integration at the data processing level**: this level of integration assures that the current estimated and predicted traffic conditions are determined by the same facilities for all ATT-applications;

5. **integration at the central control level (co-ordination)**: integration at the control-level ensures the comparability of the implemented control strategies for co-ordinated tools and applications. Additionally, conceivable synergetic effects caused by 'competitive' tools or applications are taken into account, and resulting impacts are optimised if applicable;

6. **integration at the message distribution level**: the messages distributed to the road-users are chosen from a predetermined set for all media in which comparability is necessary.

On the one hand, the advantages of integration are in general cost-reduction by avoiding the design and implementation of overlapping functions, and improved consistency due to the use of common data and models. On the other hand, integration can lead to complex systems and necessitates a clear view on the systems' architecture.
4. **TOWARDS ASSESSMENT OBJECTIVES**

4.1. **Introduction**

The assessment objectives are set on the basis of the needs and preferences of the key-decision makers and other stakeholders. In this report, the definition of assessment objective from [11] is adopted:

*Assessment Objective:

"general criterion used by the main decision makers at different levels for making judgements about the system being assessed."

The assessment objectives summarise the purposes of validation. In this respect, aim is to identify the questions to which the decision makers must have the answers. On their part, the assessment objectives correspond to criteria for making judgements and choices.

In general, a hierarchy can be identified from more general assessment objectives to more specific assessment objectives. They may range from assessment objectives such as assessing the effects of the application on the comfort of drivers, the reliability of the transport system, to the probability that road-users encounter congestion.

The assessment objectives relate closely to the implementation and the utilisation of the application. Note that the assessment objectives are not necessarily the same as the application (design) objectives. The scope of the assessment objectives is in general much broader than the scope of the design objectives, since the assessment objectives incorporate all the objectives and effects of the application implementation, i.e. the design objectives, as well as other objectives of public authorities, operators and end-users of the application.

In the remainder of this report, the assessment objectives are translated into specific experimental objectives for trial or demonstration. For example, the assessment objective increasing the safety of the traffic system may become the experimental (validation) objective establish reduction in the number of incidents. Eventually, these experimental objectives for verification and demonstration are described in terms of indicators, which are either directly or indirectly measurable, or can be derived from measurements, e.g. *the number of incidents per hour.*

In this section, the general assessment objectives for the different traffic control tools and applications are described. First, general assessment objectives and their relationship to the distinct decision-makers and users are presented. These assessment objectives reflect both the direct needs and requirements of the key decision-makers and their indirect preferences reflecting interests of key-users on whose behalf the decision-makers operate.

Secondly, the relation between these general assessment objectives, and the applications and functions presented in the previous sections are given. By using this approach, a high level of coherence between both common applications and sites is obtained.
4.2. General Assessment Objectives in DACCORD

In this section, the *general assessment objectives* which can be identified with respect to the DACCORD ATT-applications are identified. The general assessment objectives identified are based on both an analysis of the needs and requirements of users and decision-makers and concise analysis of the *use* and *implementation* of the different applications.

4.2.1. **Summary of General Assessment Objectives**

In Table 7, the assessment objectives and their relation to the different user-groups - and to the decision makers - are summarised. By comparing Table 6 and Table 7, it can be seen that the application objectives are a subset of the identified general assessment objectives. However, as mentioned earlier, the scope of assessment objectives is broader than the scope of application objectives.
4.2.2. Some Notes concerning the General Assessment Objectives

Clearly, Table 7 reflects the different application objectives identified in the previous section. However, the relation between the assessment objectives and the user-needs may not be clear at first. Therefore, we explicitly discuss this relation.

---

6The sensitivity of an application defines the degree of performance degradation due to errors in the input to the application. E.g. a predictive optimisation controller may or may not suffer from bad input data, due to poor estimation of the current state of the system.
4.2.2.1. Policy Makers

The policy makers have their own needs. Primarily, they need to know whether co-ordinated control influences traffic conditions, as well as whether the implemented applications affect the road-users positively. These are reflected by the assessment objectives related to the system-operators and the road-users.

However, giving answers to all of the questions concerning 'meeting decision makers' objectives is beyond the scope of the DACCORD evaluation. For example, in the case of the policy makers, the interest in concertation mechanisms for early resolutions of regional or administrative conflicts is beyond consideration.

4.2.2.2. Network Operators

Also the network operators have an interest in the probable effects of implementation of the candidate ATT-applications. This is reflected in the assessment objectives regarding the system-operators and the road-users. Additionally, they need insight in a number of technical aspects of the ATT-applications, such as the reliability of the installations, the extendibility, and the flexibility of the transportation control-system, reflected by their own assessment objectives.

4.2.2.3. System Operators & Road Users

User needs of both system operators and road-users are addressed through the needs and requirement of policy makers (for the road users) and network operators (for the system operators). Most of these needs are reflected directly in the assessment objectives, except those that are beyond the scope of evaluation in DACCORD.

4.2.2.4. Victims or non-users

The impacts on victims are in general looked after by the policy makers. The assessment objective is self-explanatory.

4.3. Relating Assessment Objectives to Applications

The following tables show the connection between the assessment objectives, and the control tools and applications. When applicable, a table shows these dependencies for more than one application.

Note that the assessment objectives of the policy makers (1,2), and the assessment objectives of the network-operators (3,4) are - more or less - applicable to all applications developed and/or implemented in the course of the DACCORD project. Therefore, they will not be explicitly listed. The same is observed for the assessment of the technical functioning and reliability (5), and the acceptance of the road-operator (14).

The following table indicates the relation between the different assessment objectives listed in the previous section, and the ATT-applications concerned. These general assessment objectives are generic, that is they apply to all DACCORD sites.
For data collection, data cleaning, section-level and network state-estimation, the following table has been prepared (omitting generic assessment objectives 1-5, and 14):

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<thead>
<tr>
<th>Application</th>
<th>Ass. Obj.</th>
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<th>7</th>
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</table>

Table 8: Assessment Objectives for Data Collection, Cleaning, and Estimation

Next, the table connecting the assessment objectives to the different applications for traffic control is given. Again, the assessment objectives 1-5, and 14 apply to all applications.

<table>
<thead>
<tr>
<th>Application</th>
<th>Ass. Obj.</th>
<th>6</th>
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</table>

Table 9: Assessment Objectives for Control-Applications

4.4. Categories of Assessment

After defining the assessment objectives for the different ATT-applications, the next step is to categorise the objectives into different categories of assessment. This is done in this section.

The assessment categories have been chosen in agreement with the decision-makers relevant to the DACCORD project, such that they suit the previously determined assessment objectives. Also, the characteristics of the reference system, e.g. alternative candidate control tools and applications, or the availability of a zero-situation (situation before implementation of the application), and available resources, have been taken into consideration when determining the relevant assessment objectives for the DACCORD program.

Before continuing, recall the definition of an assessment category from the draft evaluation plan:

5The assessment objectives involving the road-users can be described as 'indirect', implying that due to improvement in estimates and predictions of traffic states, traffic on the network can be actuated more efficiently, and hence the road-users benefit, e.g. the safety of the road-user may be increased by improved congestion detection.
In general seven types of assessment objectives are identified, that is technical assessment, user-acceptance assessment, impact assessment, socio-economic assessment, financial assessment, market assessment and legal- or institutional assessment. However, only four are appropriate within the DACCORD context:

1. **technical assessment**: addresses the assessment of the technical functioning of the system. For the DACCORD project, this involves among others the technical functioning of the monitoring system, the level of accuracy of the traffic-state estimations, and the technical reliability of the connection to an external traffic control centre.

2. **user-acceptance assessment**: estimation of the users' attitude to and perception of the systems and candidate systems, usually based on results from structured questionnaires, and interviews. In DACCORD, user acceptance assessment primarily concern itself with the user-acceptance of the system-operators with respect to the different ATT-applications being developed and implemented. Usually, the result of dedicated technical assessments of the ATT-application, and an impact assessment study, should determine the acceptance-level of the system operators.

   It is highly unlikely that user-acceptance studies are performed for either the road-users or the victims of the transportation system, due to budgetary restraints. However, user acceptance results from comparable evaluation studies, or from evaluation studies performed at the DACCORD test-sites by the site-managers themselves (without 'DACCORD funding') may be incorporated in the final evaluation results.

3. **impact assessment**: the determination of the effects on safety, environmental conditions, the efficiency of the transportation system, etc., caused by the implementation of the ATT-application, usually by determining changes in the values in so-called 'indicators of performance' with respect to a 'base' or 'reference case'.

   Within the impact assessment performed in DACCORD, impact on the efficient use of the infrastructure, impact on the safety, and impact on the assessment of the road-users are sub-categories in the impact assessment within DACCORD.

4. **socio-economic assessment**: estimation of the social and/or economic gains of implementing a candidate application in comparison with the current, or alternative candidate applications. Again, the gains or losses are determined by appropriate indicators of performance, including both direct and indirect costs and benefits - but also non-monetary factors -, which are determined in a later stage of the preparation of the evaluation plan. The two principle approaches generally taken are cost-benefit analysis, and multicriteria analysis.

Results from the different assessment categories applicable to the DACCORD project are inputs to other assessments in a different assessment category. For example, the results of both impact assessment (e.g. the impact of the ramp-metering installation on the effective capacity of the road), and a technical assessment (does the ramp-metering installation function properly) are inputs for a user-acceptance analysis (how does the road-operator perceive the effectiveness and efficiency of the ramp-metering installation, and hence does the road-operator intend to use ramp-metering installation giving its present functioning).
Alternatively, the ability to perform assessment studies in a specific category may pose additional constraints on other assessment studies in other assessment categories.

Figure 7 shows the dependencies (provision of results or imposing requirements) for the different DACCORD assessment categories. Furthermore, the requirements and restrictions imposed by both alternative candidate applications and limited resources are indicated as well.

Figure 7: Data-Flows from different Categories of Assessment. The arrows in the figure indicate the provision of results from one process to another. For each arrow, an opposite arrow could be draw indicating conditions imposed on a process by another process.

4.5. Pre-Assessment: Anticipated Impacts for each Application

Assessment aims to verify whether the intended impacts and effects result from the implementation of the different control tools and applications. Neither the project, nor the evaluation can be properly designed within some idea of the nature and scale of the likely impacts.

Therefore, the expected system impacts from implementation of the DACCORD applications have been identified. Moreover, the approximate magnitude of these expected impacts have been assessed.

The resulting anticipated impacts of each application on each of the identified user-groups, are given in the following tables. Whenever possible and applicable, common expected impacts have be identified for common applications, in order to maximise the integration at application level.

As a final remark, note that only the impacts (e.g. travel times, frequency and severity of congestion, safety, environmental impacts, etc.) are a part of pre-assessment. Hence, issues regarding the technical functioning of the system (accuracy, reliability, sensitivity), are not accounted for in this pre-assessment, although they can significantly influence the magnitude of the impacts, as is described in the following sections.
4.5.1. Generic Impacts
The following table indicates which specific impacts are denoted by the generic — is this respect user-group independent — terms operation/functioning, economics/efficiency, safety, behaviour, and quality/comfort. These specific impacts refer to the specific interest from each user-group. For example, improvement in operation for road-users in general refers to improvements in travel times.

<table>
<thead>
<tr>
<th>User Group</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gener. Impact</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation / Functioning</td>
<td>travel times of road-users</td>
<td>congestion</td>
<td>congestion</td>
<td>travel time, congestion</td>
<td>N/A.</td>
</tr>
<tr>
<td>Economics / Efficiency</td>
<td>cost effectiveness and efficiency of application</td>
<td>cost effectiveness and efficiency of application</td>
<td>effective capacity of road or transportation network</td>
<td>travel cost</td>
<td>fuel consumption</td>
</tr>
<tr>
<td>Safety</td>
<td>objective and subjective safety</td>
<td>objective safety</td>
<td>objective safety</td>
<td>subjective safety</td>
<td>N/A.</td>
</tr>
<tr>
<td>Behaviour</td>
<td>policy making</td>
<td>policy translation, facility provision</td>
<td>traffic control decision-making</td>
<td>re-routing</td>
<td>showing disagreement with policy makers</td>
</tr>
<tr>
<td>Quality / Comfort</td>
<td>reliability of the transport system</td>
<td>reliability of the transport system</td>
<td>reliability of means to control, ergonomics of information provision system</td>
<td>reliability, ergonomics information provision</td>
<td>level of pollution, noise level</td>
</tr>
</tbody>
</table>

Table 10: Generic Impacts and Translation to User-Group Specific Impacts

4.5.2. Expected Impacts of Data Collection, Cleaning, and Estimation Systems
Data collection, data cleaning, and both section- and network-level estimation systems play an awkward role when defining expected impacts, especially since the main interest when assessing these systems usually comprises the technical functioning of these systems, which is a technical evaluation task, and hence not a part of impact assessment.

However, improving the functioning of these systems may have indirect results on the functioning and efficiency of the transportation system, as will be discussed in the sequel of this section.

4.5.2.1. Data Collection Systems
Improvements in the technical functioning of the data collection system can lead to indirect benefits with respect to the improved functioning of data cleaning systems, state-estimation- and control systems. For example, by extending the coverage of the data collection system (the number of inductive loops on the network), or by improving the accuracy and reliability of single inductive loops, the estimates of the traffic states resulting from either the section- or station-level or network level estimation systems may be improved. This improved estimate may (or may not) significantly improve the efficiency of the control strategies generated by the network-traffic control systems (see section on the description of applications). The figure below aims to elucidate these remarks.
The extent to which the data collection system causes these indirect benefits, does not only depend on the quality of the data-collection systems and subsystems, but also on the sensitivity of the subsystem receiving the input. Clearly, this sensitivity is a property of the input-receiving subsystem, not of the input-generating data collection system.

Therefore, in the tables describing the expected impact of implementing and operating the ATT-application, only the direct impacts are depicted. Indirect impacts can be related to the expected impacts of the corresponding input-receiving subsystems, by means of the yet-to-be determined sensitivity of these subsystems.

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<tr>
<th>User Group</th>
<th>Gener. Impact</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation / Functioning</td>
<td>(+)*</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Economics / Efficiency</td>
<td>(+)</td>
<td>(+)</td>
<td>(0)</td>
<td>(+)</td>
<td>(+)</td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
<td></td>
</tr>
<tr>
<td>Behaviour</td>
<td>N/A.</td>
<td>N/A.</td>
<td>(0)</td>
<td>(0)</td>
<td>N/A.</td>
<td></td>
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<tr>
<td>Quality / Comfort</td>
<td>(+)</td>
<td>(+)</td>
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</table>

*If the expected magnitude of the impact is between brackets, the expected impact on the particular issue is indirect. Since the exact magnitude of these indirect impacts depends on the sensitivity of the subsystems, no distinction between e.g. positive, and very positive can be made.

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4.5.2.2. Expected Impacts of Data Cleaning Systems

For data cleaning, the same remarks made for data collection systems can be made with respect to indirect impacts. However, since the data-cleaning system receives

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Figure 8: Indirect Impact of Data Collection Inaccuracies
input of the data collection application, its performance is (also) dependent on the performance of the data collection system.

As mentioned, the sensitivity of the data cleaning system with respect to error-prone input from the data collection system plays a crucial role. In general, aim of data cleaning is to correct false or missing data. Consequently, data cleaning systems are designed to have low sensitivity with respect to inaccuracies and omissions in the data provided by the data collection system.

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<th>User Group</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation / Functioning</td>
<td>(+)</td>
<td>(+)</td>
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<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Economics / Efficiency</td>
<td>(+)</td>
<td>(+)</td>
<td>(0)</td>
<td>(+)</td>
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</tr>
<tr>
<td>Safety</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Behaviour</td>
<td>N/A.</td>
<td>N/A.</td>
<td>+</td>
<td>(0)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Quality / Comfort</td>
<td>(+)</td>
<td>(+)</td>
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Table 12: Expected direct and indirect Impacts of Data-Cleaning Systems

4.5.2.3. Expected Impacts of Section-Level Estimation

For section-estimation systems, the same remarks can be made, as for the data-cleaning system. Again, the performance of both the data collection and the data cleaning systems affect the performance of the section-level estimation system.

The objective of the section-level estimation is to determine various quantities, such as static queue length, and capacity, which cannot readily be measured, but have to be calculated from (cleaned) measurements. These derived quantities are either used by the network-state estimation system, or by the control system directly.

Note that the section-level estimation systems do not necessarily try to improve on the data any further, opposing to the objective of the data cleaning system. Hence, the sensitivity of the system need not necessarily be low, implying that, in principle — although undesirable and unlikely —, cleaned data with relatively high accuracy may very well lead to poor section- or station-level estimates.

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<tr>
<th>User Group</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users</th>
<th>Victims</th>
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</thead>
<tbody>
<tr>
<td>Operation / Functioning</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Economics / Efficiency</td>
<td>(+)</td>
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<tr>
<td>Safety</td>
<td>(+)</td>
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<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Behaviour</td>
<td>N/A.</td>
<td>N/A.</td>
<td>+</td>
<td>(0)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Quality / Comfort</td>
<td>(+)</td>
<td>(+)</td>
<td>+</td>
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</tr>
</tbody>
</table>

Table 13: Expected direct and indirect Impacts for Section-Level Estimation

4.5.2.4. Expected Impacts of Network-Level Traffic Estimation and Prediction

Error-prone results from both the data cleaning subsystem, and the section-level estimation subsystems, influence the performance of the network-level traffic estimation and prediction systems. The extent of this performance degradation depends on the sensitivity of the network-level traffic state estimation system, and the magnitude of the inaccuracies of the input-providing subsystems.
Note that the general aim of implementing a network-level traffic-state estimation system is to improve on the (cleaned) data, and section-state estimates of performance, capacity, queue-lengths, etc., and provide network-state predictions, by combining models describing traffic operations on the network, and both current and historic data.

Therefore, the system’s sensitivity of the system with respect to inaccuracies in the received data should be small.

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<tr>
<th>User Group</th>
<th>Policy Makers</th>
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<th>Road-Users</th>
<th>Victims</th>
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<tr>
<td>Gen. Impact</td>
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<td>(+)</td>
<td>(+)</td>
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<tr>
<td>Operation / Functioning</td>
<td>(+)</td>
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<td>(+)</td>
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<td>(+)</td>
</tr>
<tr>
<td>Economics / Efficiency</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Safety</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Behaviour</td>
<td>N/A.</td>
<td>N/A.</td>
<td>++</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Quality / Comfort</td>
<td>(+)</td>
<td>(+)</td>
<td>++</td>
<td>(+)</td>
<td>(+)</td>
</tr>
</tbody>
</table>

++: very pos. impact +: positive impact 0: neutral impact -: negative impact --: very neg. impact

Table 14: Network Level-Traffic Estimation and Prediction

4.5.5. Expected Impacts of Traffic Control

In the following we discuss the expected impacts which section traffic control, point traffic control, and network traffic control, have on the transportation system operating conditions.

In comparison to the input-generating data collection, data cleaning, estimation and prediction systems, the traffic control systems have a direct impact on traffic operations. The performance of these systems is frequently related directly to the magnitude of the impact on the traffic operations. However, the factors which influence this performance are numerous, and often exogenously or partially determined by the control system. Examples of these factors are the inaccuracies in input-data (e.g. state estimates), reaction of drivers to either descriptive or prescriptive information (compliance of the drivers), traffic demand, traffic composition, route choices, etc.

Furthermore, flaws in both methodology determining the control laws (for example, due to inaccuracies in the model results necessary for predictive control), and the technical functioning of the actuators, are factors which are intrinsic of the control systems.

In the tables presenting the expected impacts of the section traffic, localised area, and network traffic control, the expected direct impacts of implementation and operation of the applications for traffic control are depicted, given reasonable and realisable conditions of the state-estimation, the driver compliance, etc. Next, for each of the control-types, the expected impacts are depicted.
4.5.3.1. Section Traffic Control

<table>
<thead>
<tr>
<th>User Group →</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen. Impact 0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Table 15: Expected Impacts of Speed Regulation System**

4.5.3.2. Point Control

When considering localised area control, the road-users using the interurban transportation network have been divided into classes having their origins and destinations either in the underlying urban network (U), or traffic which have originated from or are destined to other parts of the interurban network.

<table>
<thead>
<tr>
<th>User Group →</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users</th>
<th>Road-Users U→U</th>
<th>Road-Users I→I</th>
<th>Road-Users I→I</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gen. Impact 0</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>N/A</td>
</tr>
</tbody>
</table>

**Table 17: Expected Impacts (co-ordinate) Ramp-metering**
The integration of applications, estimation and prediction tools, and the connection with other (external) Traffic Control Centres, do not have direct 'impacts' on the network traffic operations, just like the data-collection, data cleaning, and the estimation tools. The following tables represent the expected impacts for these tools:

Table 18: expected Impacts (co-ordinate) Mainline-metering

<table>
<thead>
<tr>
<th>User Group ⇔ Gen. Impact 0</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users U=U</th>
<th>Road-Users I=I</th>
<th>Road-Users I=I</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation / Functioning</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>N/A</td>
</tr>
<tr>
<td>Economics / Efficiency</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Safety</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>N/A</td>
</tr>
<tr>
<td>Behaviour</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N/A</td>
</tr>
<tr>
<td>Quality / Comfort</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>N/A</td>
</tr>
</tbody>
</table>

++: very pos. impact  +: positive impact  0: neutral impact  -: negative impact  --: very neg. impact  (+/0/-): indirect

Table 19: expected Impacts Network-Level Queue-Length-, and Travel-Time-Display

<table>
<thead>
<tr>
<th>User Group ⇔ Gen. Impact 0</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users (directed)</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation / Functioning</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>N/A</td>
</tr>
<tr>
<td>Economics / Efficiency</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td>0/+</td>
</tr>
<tr>
<td>Safety</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Behaviour</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Quality / Comfort</td>
<td>+</td>
<td></td>
<td>+</td>
<td>+</td>
<td>0/+</td>
</tr>
</tbody>
</table>

++: very pos. impact  +: positive impact  0: neutral impact  -: negative impact  --: very neg. impact

Table 20: expected Impacts Variable Direction Signs

<table>
<thead>
<tr>
<th>User Group ⇔ Gen. Impact 0</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users (directed)</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation / Functioning</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>N/A</td>
</tr>
<tr>
<td>Economics / Efficiency</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td>0/+</td>
</tr>
<tr>
<td>Safety</td>
<td>+</td>
<td></td>
<td>+</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Behaviour</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Quality / Comfort</td>
<td>+</td>
<td></td>
<td>+</td>
<td>++</td>
<td>0/+</td>
</tr>
</tbody>
</table>

++: very pos. impact  +: positive impact  0: neutral impact  -: negative impact  --: very neg. impact
### Table 21: expected Impacts for Integration of control Measures, and Estimation and Prediction Tools (OSS- and CTMS-systems)

<table>
<thead>
<tr>
<th>Target Group</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation / Functioning</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Economics / Efficiency</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Safety</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Behaviour</td>
<td>N/A.</td>
<td>N/A.</td>
<td>++</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Quality / Comfort</td>
<td>(+)</td>
<td>(+)</td>
<td>+</td>
<td>(+)</td>
<td>(+)</td>
</tr>
</tbody>
</table>

(+): very pos. impact, (+): positive impact, 0: neutral impact, -: negative impact, --: very neg. impact

<table>
<thead>
<tr>
<th>Target Group</th>
<th>Policy Makers</th>
<th>Network Operators</th>
<th>System Operators</th>
<th>Road-Users</th>
<th>Victims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation / Functioning</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Economics / Efficiency</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Safety</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Behaviour</td>
<td>N/A.</td>
<td>N/A.</td>
<td>++</td>
<td>(+)</td>
<td>N/A.</td>
</tr>
<tr>
<td>Quality / Comfort</td>
<td>(+)</td>
<td>(+)</td>
<td>+</td>
<td>(+)</td>
<td>(+)</td>
</tr>
</tbody>
</table>

(+): very pos. impact, (+): positive impact, 0: neutral impact, -: negative impact, --: very neg. impact

### Table 22: expected direct and indirect Impacts of the Connection with other TCC’s
PART B:

The Validation Plan: Performance Indicators & Tools for Assessment
5.  **PREPARATION OF THE VALIDATION PLAN**

5.1. Introduction

This chapter explains the steps taken for preparation of the validation plan. It provides a connection between the general assessment objectives determined in the previous chapter, and the performance indicators derived in the following chapter, by proposition of validation objectives.

Before continuing, we clarify the distinction between evaluation, and validation. Therefore, the definition of validation from the draft evaluation plan is recalled:

*Validation* "the process of testing how an ATT-application performs with respect to the distinguished assessment objectives"

Validation essentially consists of two distinct stages: verification and demonstration:

*Verification* "the first stage of validation. Verification is in general not conducted under (full) operational conditions. It concerns testing the physical functioning of the application and acceptance of the application by its main users. Additionally, it may be necessary to conduct preliminary tests of user-acceptance by other end-users”

The verification stage should provide sufficient justification to proceed to the more comprehensive demonstration stage. In order to assure a reasonable level of confidence on the results from the verification stage, requirements are posed. These requirements on verification consist of:

1. testing the *operating performance* of the application (technical assessment);
2. provision of reasonable evidence with respect to the acceptance by the network- and system-operators (user-acceptance assessment);
3. provision of sufficient *impact analysis* to assure the European Commission and other decision makers about the likely performance of the ATT-system with respect to the assessment objectives.

For the demonstration stage, the following definition is used:

*Demonstration* “the second stage of validation. It is conducted under operational conditions and concentrates on acceptance of the application by a larger sample of end-users and comprehensive impact analysis in order to evaluate the benefits of the application”

Hence, the demonstration stage will:

1. testing the performance of the control tools and applications under full operational conditions;
2. verify the *acceptance* of the control tools and applications by the network- and the system-operators;
3. provide results of a (more) comprehensive impact analysis to verify the performance of the applications with respect to the assessment objectives to the European Commission and other decision makers of the tools and applications;
4. assess the cost-effectiveness of the implemented applications.

The following scheme depicts the structure of validation of the applications.
In this report, the validation plan for the DACCORD test-sites is formulated. If applicable, the validation plan for common applications at the different test-sites is site-independent, ensuring maximisation of cross-site comparison potential.

The methodology presented in the draft evaluation plan has been applied to all control tools and applications at each test-site. The results can be found in the following sections and chapters.

5.2. Validation Objectives

The first results presented are the experimental assessment objectives for verification and demonstration - referred to as the validation objectives - resulting from synthesis and analysis of both the general assessment objectives, and the expected impacts, both presented in part A.

Furthermore, the validation objectives have been associated by all the user-groups affected by implementation of the ATT-application. Additionally, the results of the pre-assessment have been used. Finally, the different validation objectives have been grouped into the four assessment categories identified in the DACCORD evaluation.

5.2.1. European Added Value, Transferability, Extendibility, and Flexibility

The general assessment objectives:
• to assess the transferability or applicability of methodologies to a wide range of (European) sites, regardless of variations in topology, geometry, and traffic characteristics;

• to assess the extendibility and flexibility of the resulting traffic management system;

are applicable to all ATT-applications to be implemented.

Apart from the general relevance of these assessment objectives, they also reflect the European Added Value of the DACCORD project. Translating these general assessment objectives into specific experimental objectives results in generic — that is application independent — validation objectives:

<table>
<thead>
<tr>
<th>Users Involved</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Policy Makers, Network Operators</td>
<td>1. the transferability or applicability of methodologies to a wide range of (European) sites, regardless of variations in topology, geometry, and traffic characteristics</td>
<td>• the extent of transferability of the different control tools and applications and methodologies with respect to the DACCORD test-sites by comparing implemented applications and underlying architectures, and possibilities of implementing applications and methodologies of the other sites</td>
</tr>
<tr>
<td>Policy Makers, Network Operators</td>
<td>2. the extendibility and flexibility of the resulting traffic management system</td>
<td>• the possibility of extending the control system by additional parts of the network, or additional ATT-applications</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• the possibility of adjusting application objectives and constraints after implementation of the applications</td>
</tr>
</tbody>
</table>

Table 23: Generic Validation Objectives for Transferability, Extendibility, and Flexibility

Both the transferability and the extendibility of the system are general DACCORD objectives. Not only do they involve assessment of the DTM-applications and their impacts, but also assessment of the architectural structure of the transportation system. Hence, the extent in which these assessment objectives can be reached within this evaluation phase of the DACCORD programme is limited. Possibly, user-acceptance analysis could be useful to provide answers to questions raised by these issues.

5.2.2. Generic Validation Objectives for control tools and applications

In this subsection, the generic validation objectives, that is the validation objectives which can be formulated for a whole range of ATT-applications, are presented. Tables presented in the previous chapter can be applied to consolidate the validation objectives to the relevant ATT-applications, and the relevant decision-makers, and user-groups.

The following tables indicate for each validation objective:

1. the relevant category of assessment;

2. the general assessment objective from which the validation objective has been derived.
<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
</table>
| Socio-Economic Evaluation | 3. the impact of implementation of the application on the cost-effectiveness of the transportation network | a) the extent of the improvement or degradation of the cost-effectiveness of the transportation network due to the DACCORD tools and applications  
   b) whether the improvement in the effectiveness of the ATT-application validates the cost of implementation, running and maintenance of the application (multi-criteria analysis) |
| Technical Assessment | 4. the impact of implementation of the application on the efficiency of the transportation system | a) the extent of the improvement or degradation of the efficiency of the transportation network of the DACCORD ATT-applications by means of impact assessment and socio-economic evaluation (cost-benefit analysis) |
| Technical Assessment | 5. to assess the technical functioning and technical reliability of the ATT-application | a) whether the technical functioning and the reliability of the ATT-application complies to the accepted technical standard by studying systems' delay  
   b) whether the technical functioning and the reliability of the ATT-application complies to the accepted technical standard by studying systems' failure rate |

Table 24: Generic Validation Objectives

### 5.2.3. Application-specific validation Objectives for Data Collection, Data Cleaning and Estimation Systems

This subsection on validation objectives presents the resulting application-specific validation objectives for data collection, data cleaning, and (state-) estimation systems.

#### 5.2.3.1. Data Collection

For data collection, the main expected impacts are improvement of the reliability of information provided by the applications to other ATT-tools and applications.

<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Assessment</td>
<td>6. to assess the effects of the application on the provision of reliable measurements for operators and/or subsystems</td>
<td>a) whether the quality (accuracy) of the provided measurements of the application have improved/complies to a technical standard accepted by system operators</td>
</tr>
</tbody>
</table>

Table 25: validation Objectives for Data Collection Systems

#### 5.2.3.2. Data Cleaning, Section- and Network-Level Estimation

With respect to both data cleaning, and estimation, the primary expected impacts which have been determined are changes in the behaviour of the operators due to provided information. It is expected that, due to improved information provision, the operators can actuate traffic more effectively, that is if the accuracy of the provided information complies to an acceptable standard, thereby assuring the confidence of the operators. Additionally, the way in which the information is provided (Human-Machine-Interface) is very important for improved operation.
<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Assessment</td>
<td>7. to assess the sensitivity of the application</td>
<td>a) the level of change in the output of the ATT-application caused by small perturbations in the input of the application</td>
</tr>
<tr>
<td></td>
<td>8. to assess the improvement in the quality and/or quantity of data for operators and/or subsystems</td>
<td>a) whether the quality (accuracy) of the data provided by the application have improved/complies to an accepted technical standard</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) whether the ATT-application improves the quantity of available data (data cleaning phase) which comply to an accepted technical standard</td>
</tr>
<tr>
<td>User-Acceptance Analysis</td>
<td>11. to assess the improvement in provision of assistance for decision making by road-operators</td>
<td>a) level of confidence in/acceptance of information provided by the ATT-application</td>
</tr>
<tr>
<td></td>
<td>12. to assess the flexibility and ergonomics of the Human-Machine-Interface (HMI)</td>
<td>a) level of quality / ergonomics of the information provision system about the state of the transportation network</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) whether the ergonomics / flexibility for intervention by the operator are off an acceptable standard</td>
</tr>
</tbody>
</table>

Table 26: Validation Objectives for Data Cleaning Systems

<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Assessment</td>
<td>7. to assess the sensitivity of the application</td>
<td>a) the level of change in the output of the ATT-application caused by small perturbations in the input of the application</td>
</tr>
<tr>
<td></td>
<td>9. to assess the improvement in the quality of information on the current or predicted traffic (network-) state for operators and subsystems</td>
<td>a) whether the quality (accuracy) of the network state-estimation or prediction provided by the application have improved/complies to an accepted technical standard</td>
</tr>
<tr>
<td>User-Acceptance Analysis</td>
<td>11. to assess the improvement in provision of assistance for decision making by road-operators</td>
<td>a) level of confidence in/acceptance of information provided by the ATT-application</td>
</tr>
<tr>
<td></td>
<td>12. to assess the flexibility and ergonomics of the Human-Machine-Interface (HMI)</td>
<td>a) level of quality / ergonomics of the information provision system about the state of the transportation network</td>
</tr>
<tr>
<td></td>
<td></td>
<td>b) whether the ergonomics / flexibility for intervention by the operator are off an acceptable standard</td>
</tr>
</tbody>
</table>

Table 27: Validation Objectives for Section-Level Estimation
### Table 28: Validation Objectives for Network-Level Estimation & Prediction

<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Assessment</td>
<td>7. to assess the sensitivity of the application</td>
<td>a) the level of change in the output of the ATT-application caused by small perturbations in the input of the application</td>
</tr>
<tr>
<td></td>
<td>9. to assess the improvement in the quality of information on the current or predicted traffic (network-) state for operators and subsystems</td>
<td>a) whether the quality (accuracy) of the network state-estimation or prediction provided by the application have improved/complies to an accepted technical standard</td>
</tr>
<tr>
<td>User-Acceptance Analysis</td>
<td>11. to assess the improvement in provision of assistance for decision making by road-operators</td>
<td>a) level of confidence in/acceptance of information provided by the ATT-application</td>
</tr>
</tbody>
</table>
|                        | 12. to assess the flexibility and ergonomics of the Human-Machine-Interface (HMI) | a) level of quality/ergonomics of the information provision system about the state of the transportation network  
b) whether the ergonomics/flexibility for intervention by the operator are off an acceptable standard |

#### 5.2.4. Application-specific validation Objectives for Traffic Control-Applications

The last subsection on validation objectives presents resulting application-specific experimental objectives for traffic control applications.

##### 5.2.4.1. Speed Regulation Control

Expected impact assessment for speed regulation control results in expected improvements in both safety (subjective and objective), and the reliability of the transportation system. Although no significant improvements in the efficiency of the transportation systems are expected, it is still interesting to assess changes in efficient capacity, and especially frequency and severity of congestion, due to the homogenising effect of speed regulation (see [23]). Additionally, expected improvements in fuel consumption, and level of pollution are reflected by the validation objectives as well. Finally, from an operators' perspective, the effectiveness and efficiency of speed-regulation control should also be assessed. Again, ergonomy of the HMI is required.
<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Assessment</td>
<td>7. to assess the sensitivity of the application</td>
<td>a) the level of change in the output of the ATT-application caused by small perturbations in the input of the application</td>
</tr>
</tbody>
</table>
| Impact Assessment      | 10. to assess the effectiveness of the application as a means to actuate traffic | a) level of effectiveness of the ATT-applications as a means to control traffic by analysis of compliance rate of road users, i.e.:  
  • level of change in average speed with respect to recommended speed |
| User Acceptance analysis | 12. to assess the flexibility and ergonomics of the Human-Machine-Interface (HMI) | a) level of quality / ergonomics of the information provision system about the state of the transportation network  
  b) whether the ergonomics / flexibility for intervention by the operator are off an acceptable standard |
| Impact Assessment      | 13. to assess the impact of the implementation of the application on the effective network- and/or road-capacity, and the efficient use of (existing) infrastructural facilities | a) level of change in effective road-capacity of a section, due to improved use of infrastructural facilities  
  b) level of change in frequency and severity of congestion due to improvements in the effective road-capacity, or homogenising traffic flow |
| User Acceptance analysis | 14. to assess the acceptance of the application by the road-user | a) compliance level of road-users to speed regulation-settings |
| Impact Assessment      | 15. to assess the decrease in travel time losses due to congestion or rerouting | a) level of change in travel-time losses due to congestion through changes in effective road-capacity (for distinct user-groups) |
| User Acceptance/Technical Assessment | 16. to assess the improvement in assistance of the road-users | a) improvement in the information coverage ratio (penetration) due to implementation of the ATT-application  
  b) level of improvement in the reliability of the information provided |
| Impact Assessment      | 17. to assess the improvement in the safety of the road-users, and the improvement in their behaviour (number of violations and other kinds of incorrect behaviour) | a) the level of change in the number of reported accidents and incidents  
  b) the level of change in the impedance (hindering) of the road-user |
|                        | 18. to assess the improvement in the reliability of the transportation system | a) level of change in the variability of travel times and travel time losses due to:  
  • improvements in effective road-capacity  
  • homogenising effect of speed-recommendation |
|                        | 19. to assess the effects of implementation of the application on the environment:  
  • level of pollution  
  • fuel consumption | a) level of change in exhaust gas emissions due to implementation of the application  
  b) level of change in fuel consumption due to implementation of the application |

**Table 29: Validation Objectives for Speed-Regulation Control**

5.2.4.2. Lane Usage Control

From analysis of anticipated impacts, lane usage control is envisaged to be beneficial for improvement in safety of the road-users. Additionally, improvements in efficiency, due to allocation of infrastructure to road-user-classes on social or
economical grounds, e.g. freight transport, business related traffic (see [24]), may results in reduction of fuel-consumption and pollution. Additionally, improvements in the reliability of the transportation system (for distinct road-user classes) are envisaged. Finally, from an operators' perspective, the effectiveness and efficiency of lane-usage control should be assessed as well, again with ergonomy of the HMI as a requirement.

<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess</th>
<th>Validation Objective to establish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Assessment</td>
<td>7. to assess the sensitivity of the application</td>
<td></td>
</tr>
<tr>
<td>Impact Assessment</td>
<td>10. to assess the effectiveness of the application as a means to actuate traffic</td>
<td></td>
</tr>
<tr>
<td>User Acceptance analysis</td>
<td>12. to assess the flexibility and ergonomics of the Human-Machine-Interface (HMI)</td>
<td></td>
</tr>
<tr>
<td>Impact Assessment</td>
<td>15. to assess the impact of the implementation of the application on the effective network- and/or road-capacity, and the efficient use of (existing) infrastructural facilities</td>
<td></td>
</tr>
<tr>
<td>User-Acceptance analysis</td>
<td>14. to assess the acceptance of the application by the road-user</td>
<td></td>
</tr>
<tr>
<td>Impact Assessment</td>
<td>15. to assess the decrease in travel time losses due to congestion or rerouting</td>
<td></td>
</tr>
<tr>
<td>User-Acceptance/Technical Assessment</td>
<td>16. to assess the improvement in assistance of the road-users</td>
<td></td>
</tr>
<tr>
<td></td>
<td>17. to assess the improvement in the safety of the road-users, and the improvement in their behaviour (number of violations and other kinds of incorrect behaviour)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18. to assess the improvement in the reliability of the transportation system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19. to assess the effects of implementation of the application on the environment:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• level of pollution</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• fuel consumption</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) the level of change in the output of the ATT-application caused by small perturbations in the input of the application</td>
</tr>
<tr>
<td>a) level of effectiveness of the ATT-applications as a means to control traffic by analysis of compliance rate of route users, i.e.:</td>
</tr>
<tr>
<td>• level of change in average speed with respect to recommended speed;</td>
</tr>
<tr>
<td>• compliance to lane-use control settings</td>
</tr>
<tr>
<td>a) level of quality/ergonomics of the information provision system about the state of the transportation network</td>
</tr>
<tr>
<td>b) whether the ergonomics/ flexibility for intervention by the operator are on an acceptable standard</td>
</tr>
<tr>
<td>a) level of change in effective road-capacity of a section, due to improved use of infrastructural facilities</td>
</tr>
<tr>
<td>a) compliance level of road-users to lane-usage settings</td>
</tr>
<tr>
<td>a) level of change in travel-time losses due to congestion due to changes in effective road-capacity (for distinct user-groups)</td>
</tr>
<tr>
<td>a) improvement in the information coverage ratio (penetration) due to implementation of the ATT-application</td>
</tr>
<tr>
<td>a) the level of change in the number of reported accidents and incidents</td>
</tr>
<tr>
<td>b) the level of change in the impedance (hindering) of the road-user</td>
</tr>
<tr>
<td>a) level of change in the variability of travel times and travel time losses due to:</td>
</tr>
<tr>
<td>• improvements in effective road-capacity</td>
</tr>
<tr>
<td>a) level of change in exhaust gas emissions due to implementation of the application</td>
</tr>
<tr>
<td>b) level of change in fuel consumption due to implementation of the application</td>
</tr>
</tbody>
</table>

Table 30: Validation Objectives for Lane Usage Control
5.2.4.3. Point Control

For metering control — either isolated, or integrated at a specific level of integration or co-ordination — analysis of expected impacts has shown that significant benefits are foreseen in improvement of the efficient use of the facilities, either by increasing the effective capacity due to peak-shaving effects, or by re-routing of traffic. Additionally, the reliability of the transportation system should increase — at least for drivers on the freeway — due to smoothing of traffic demand at on-ramps.

The magnitude of changes in the subjective or objective safety remain unclear, due to competitive effects of metering control: on the one hand, improved merging behaviour of road-user increases safety, e.g. due to the proportional decrease of very small values in time to collision. On the other hand, re-routing effects may result in higher traffic demand for the underlying urban networks, or secondary roads, which are in general relatively unsafe in comparison to the freeway network. The latter would result in a decrease of the safety.

Finally, metering installations provide the operators with means to actuate traffic effectively and efficiently. Again the ergonomics of the HMI is a requirement for improved operation. This is also reflected in the validation objectives.
<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Assessment</td>
<td>7. to assess the sensitivity of the application</td>
<td>a) the level of change in the output of the ATT-application caused by small perturbations in the input of the application</td>
</tr>
</tbody>
</table>
|                        | 10. to assess the effectiveness of the application as a means to actuate traffic | a) level of effectiveness of the ATT-applications as a means to control traffic by analysis of compliance rate of route users, i.e.:  
  - compliance to the ramp-metering and mainline-metering policies |
| Impact Assessment      | 12. to assess the flexibility and ergonomics of the Human-Machine-Interface (HMI) | a) level of quality / ergonomics of the information provision system about the state of the transportation network  
  b) whether the ergonomics / flexibility for intervention by the operator are off an acceptable standard |
| Impact Assessment      | 13. to assess the impact of the implementation of the application on the effective network- and/or road-capacity, and the efficient use of (existing) infrastructural facilities | a) level of change in effective road-capacity of a section, due to peak-shaving effects  
  b) level of change in the frequency and severity of congestion due to:  
    - changes in effective road-capacity (for distinct user-groups) caused by peak-shaving  
    - changes in traffic demand due to re-routed drivers  
    - avoidance of congestion by re-routed road-users |
| User Acceptance analysis | 14. to assess the acceptance of the application by the road-user | a) compliance level of road-users to ramp-metering and mainline-metering control policies |
| Impact Assessment      | 15. to assess the decrease in travel time losses due to congestion or rerouting | a) level of change in travel time losses caused by congestion due to changes in effective road-capacity (for distinct user-groups) caused by peak-shaving  
  b) level of change in travel time losses due to changes in the frequency and severity of congestion due to decreased traffic demand due to re-routed drivers  
  c) level of change in travel time losses due to congestion by avoidance of congestion by re-routed road-users |
|                        | 17. to assess the improvement in the safety of the road-users, and the improvement in their behaviour (number of violations and other kinds of incorrect behaviour) | a) the level of change in the number of reported accidents and incidents  
  b) the level of change in the impedance (hindering) of the road-user |
|                        | 18. to assess the improvement in the reliability of the transportation system | a) level of change in the variability of travel times and travel time losses due to:  
  - improvements in effective road-capacity  
  - changed traffic demand due to re-routed drivers  
  - avoidance of congestion for re-routed drivers |
|                        | 19. to assess the effects of implementation of the application on the environment:  
  - level of pollution  
  - fuel consumption | a) level of change in exhaust gas emissions due to implementation of the application  
  b) level of change in fuel consumption due to implementation of the application |

Table 31: Validation Objectives for Point-Control
5.2.4.4. Queue-length Display, Travel Time Display, and Variable Direction Signs (Route Guidance) systems

Regarding the provision of information on either travel times, queue-lengths, or best route alternative (route guidance), pre-assessment suggests that benefits are expected in the level of effectiveness of traffic control, frequency and severity of congestion, the reliability of the transportation system, and travel time losses. Moreover, improvements in assisting the road-users, and effectiveness of the applications as a means to control traffic are also assessed. Again the ergonomics of the HMI is a requirement for improved operation.
<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Assessment</td>
<td>7. to assess the sensitivity of the application</td>
<td>a) the level of change in the output of the ATT-application caused by small perturbations in the input of the application</td>
</tr>
<tr>
<td>Impact Assessment</td>
<td>10. to assess the effectiveness of the application as a means to actuate traffic</td>
<td>a) level of effectiveness of the ATT-applications as a means to control traffic by analysis of compliance rate of route users, i.e.:&lt;br&gt;• road-users response to information on travel times/queue lengths provided by the VMS&lt;br&gt;• compliance rate of road-user to road-guidance</td>
</tr>
<tr>
<td>User Acceptance analysis</td>
<td>12. to assess the flexibility and ergonomics of the Human-Machine-Interface (HMI)</td>
<td>a) level of quality / ergonomics of the information provision system about the state of the transportation network&lt;br&gt;b) whether the ergonomics / flexibility for intervention by the operator are off an acceptable standard</td>
</tr>
<tr>
<td>Impact Assessment</td>
<td>13. to assess the impact of the implementation of the application on the effective network- and/or road-capacity, and the efficient use of (existing) infrastructural facilities</td>
<td>a) level of change in the frequency and severity of congestion due to:&lt;br&gt;• changes in traffic demand caused by re-routed drivers&lt;br&gt;• avoidance of congestion by re-routed road-users</td>
</tr>
<tr>
<td>User Acceptance analysis</td>
<td>14. to assess the acceptance of the application by the road-user</td>
<td>a) compliance rate of road-user to road-guidance&lt;br&gt;b) road-users response to information on travel times/queue lengths provided by the VMS</td>
</tr>
<tr>
<td>Impact Assessment</td>
<td>15. to assess the decrease in travel time losses due to congestion or rerouting</td>
<td>a) level of change in travel time losses due to changes in the frequency and severity of congestion caused by decreased traffic demand due to re-routed drivers&lt;br&gt;b) level of change of travel time losses due to congestion by avoidance of congestion by re-routed road-users</td>
</tr>
<tr>
<td>User Acceptance/Technical Assessment</td>
<td>16. to assess the improvement in assistance of the road-users</td>
<td>a) improvement in the information coverage ratio (penetration) due to implementation of the ATT-application&lt;br&gt;b) level of improvement in the reliability of the information provided</td>
</tr>
<tr>
<td></td>
<td>17. to assess the improvement in the safety of the road-users, and the improvement in their behaviour (number of violations and other kinds of incorrect behaviour)</td>
<td>a) the level of change in the number of reported accidents and incidents&lt;br&gt;b) the level of change in the impedance (hindering) of the road-user</td>
</tr>
<tr>
<td></td>
<td>18. to assess the improvement in the reliability of the transportation system</td>
<td>a) level of change in the variability of travel times and travel time losses due to:&lt;br&gt;• changed traffic demand due to re-routed drivers&lt;br&gt;• avoidance of congestion for re-routed drivers</td>
</tr>
<tr>
<td></td>
<td>19. to assess the effects of implementation of the application on the environment: &lt;br&gt;• level of pollution&lt;br&gt;• fuel consumption</td>
<td>a) level of change in exhaust gas emissions due to implementation of the application&lt;br&gt;b) level of change in fuel consumption due to implementation of the application</td>
</tr>
</tbody>
</table>

Table 32: Validation Objectives for dynamic Queue-length Display, Travel Time Display, and Variable Direction Signs (Route Guidance) systems
5.2.4.5. Tools for Integration and Co-ordination

Although most of the impacts due to integration and co-ordination of the different (isolated) ATC-applications are indirect, significant improvements in the average congestion level, travel times, and the reliability are expected for the road-users. Moreover, assistance of the road-user and operators is (indirectly) improved due to higher quality of the provided information regarding queue-lengths, travel times, optimal route alternatives, or incidents. Additionally, the way in which the information is provided to the operators, and the ergonomics with respect to consolidation of man and machine (Human-Machine-Interface) is a boundary condition for improved operation.
<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Assessment</td>
<td>5. to assess the technical functioning of the application</td>
<td>a) to assess the level of integration at the data collection, data storage, data processing level, and control level.</td>
</tr>
<tr>
<td></td>
<td>7. to assess the sensitivity of the application</td>
<td>a) the level of change in the output of the ATT-application caused by small perturbations in the input of the application.</td>
</tr>
<tr>
<td></td>
<td>9. to assess the improvement in the quality of information on the current or predicted traffic (network-) state for operators and subsystems</td>
<td>a) whether the quality (accuracy) of the network state-estimation or prediction provided by the application have improved/complies to an accepted technical standard.</td>
</tr>
<tr>
<td>User-Acceptance Analysis</td>
<td>11. to assess the improvement in provision of assistance for decision making by road-operators</td>
<td>a) level of confidence/acceptance of information provided by the ATT-application (e.g. regarding the predicted impacts of control measures and settings proposed by the system operators).</td>
</tr>
<tr>
<td></td>
<td>12. to assess the flexibility and ergonomics of the Human-Machine-Interface (HMI)</td>
<td>a) level of quality/ergonomics of the information provision system about the estimated and predicted state of the transportation network. b) whether the ergonomics/flexibility for intervention by the operator are off an acceptable standard.</td>
</tr>
<tr>
<td>Impact Assessment</td>
<td>13. to assess the impact of the implementation of the application on the effective network- and/or road-capacity, and the efficient use of (existing) infrastructural facilities</td>
<td>a) level of change in the frequency and severity of congestion due to improved network capacity caused by reduction of synergetic effects of isolated ATT-applications, improved re-routing, etc.</td>
</tr>
<tr>
<td>User-Acceptance Analysis</td>
<td>14. to assess the acceptance of the application by the road-operator</td>
<td>a) improved compliance rate of road-user to road-guidance due to improvements in reliability of the information provided. b) road-users response to information on travel times/queue lengths provided by the VMS due to improvements in reliability of the information provided.</td>
</tr>
<tr>
<td>Impact Assessment</td>
<td>15. to assess the decrease in travel time losses due to congestion or rerouting</td>
<td>a) level of change in travel time losses due to changes in the frequency and severity of congestion caused by to improved network capacity caused by to improved network capacity caused by to improved network capacity caused by to improved network capacity caused by to improved network capacity caused by.</td>
</tr>
<tr>
<td>User-Acceptance/Technical Assessment</td>
<td>16. to assess the improvement in assistance of the road-users</td>
<td>a) improvement in the information coverage ratio (penetration) due to implementation of the ATT-application. b) level of improvement in the reliability of the information provided.</td>
</tr>
<tr>
<td>User-Acceptance</td>
<td>17. to assess the improvement in the safety of the road-users, and the improvement in their behaviour (number of violations and other kinds of incorrect behaviour)</td>
<td>a) the level of change in the number of reported accidents and incidents. b) the level of change in the impedance (hindering) of the road-user.</td>
</tr>
<tr>
<td></td>
<td>18. to assess the improvement in the reliability of the transportation system</td>
<td>a) level of change in the variability of travel times and travel time losses due to. • changed traffic demand due to re-routed drivers • avoidance of congestion for re-routed drivers.</td>
</tr>
<tr>
<td></td>
<td>19. to assess the effects of implementation of the application on the environment: • level of pollution • fuel consumption</td>
<td>a) level of change in exhaust gas emissions due to implementation of the application. b) level of change in fuel consumption due to implementation of the application.</td>
</tr>
</tbody>
</table>
### Table 33: Validation Objectives for Integration of Control Measures, Estimation, and Prediction Tools (OSS-, and CTMS-Systems)

<table>
<thead>
<tr>
<th>Category of Assessment</th>
<th>General Assessment Objective to assess:</th>
<th>Validation Objective to establish:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Assessment</td>
<td>7. to assess the sensitivity of the application</td>
<td>a) the level of change in the output of the ATT-application caused by small perturbations in the input of the application</td>
</tr>
<tr>
<td></td>
<td>9. to assess the improvement in the quality of information on the current or predicted traffic (network-) state for operators and subsystems</td>
<td>a) whether the quality (accuracy) of the network state-estimation or prediction provided by the application have improved/complies to an accepted technical standard</td>
</tr>
</tbody>
</table>
| User-Acceptance Analysis | 11. to assess the improvement in provision of assistance for decision making by road-operators | a) level of confidence in/acceptance of information provided by the ATT-application  
b) improving the level of knowledge of the system-operator on external traffic conditions |
|                        | 12. to assess the flexibility and ergonomics of the Human-Machine-Interface (HMI) | a) level of quality/ergonomics of the information provision system about the state of the transportation network, and the remote transportation network |

### Table 34: Validation Objectives for Connection with remote Traffic Control Centres
a proposed evaluation approach
6. THE MEASUREMENT PLAN

6.1. Introduction

In this chapter, the performance indicators for the different effects of the control tools and applications are described. While outlining these indicators, the general objectives of both the DACCORD-programme, the individual applications, and the derived assessment objectives, have been taken into account. Additionally, a description of data requirements for evaluation is presented.

6.1.1. Organisation of Performance Indicators

In the previous sections of this evaluation plan, a list of validation objectives for each of which we want to specify one or more performance criteria has resulted. Performance variables, directly measured or derived from measurements or modelling, indicating the performance or impacts of an application.

The performance indicators are organised using a two-level structure (see Figure 13).

At the first level, the performance indicators are divided two classes (see [16]):

1. common indicators;
2. indicators according to the functions.

Additionally, when specifying these performance criteria data availability was considered. On the basis of the available data — usually time-series of traffic counts and speed observations — we can rarely observe the value of a performance indicator in a direct manner. Therefore, on the second level, we have subdivided the indicators according to the functions into:

- directly observed indicators (e.g. traffic volumes at a specific location);
- indirectly observed indicators (e.g. noise level, deduced by a simple model);
- derived indicators (e.g. computation of route-choices, actual travel time, etc.).

The difference between indirect and derived indicators is gradual. As a guideline, indicators are considered to be indirect if they can be derived by applying a simple rule to directly observed quantities, e.g. computing noise level from average speed and link volume, whereas the computation of derived indicators involves using many data, often combined with the usage of a model.

A part of the evaluation will be based on secondary sources: the results of investigations by third parties, reported in a document or otherwise (e.g. interview).

Note that just the calculation of performance indicators from available data does not necessarily provide a consistent evaluation procedure. Frequently, additional analysis of the performance indicators in necessary in order to provide for dependable results, for example regression analysis, stimulus-response analysis, trend-analysis. In this respect, the indicators of performance provide the building blocks for the final steps of the validation.
6.2. Data Dictionary for the Evaluation in DACCORD: Static and Dynamic Data

Before describing the various performance indicators, the data format is outlined. The data needed for evaluation is subdivided in dynamic and static network data.

6.2.1. Static data

Static data are needed to describe the fixed configuration of a traffic system, and the detectors and actuators associated with it.

The static data needed for evaluation contain information on:

- the geography of the network, i.e. position of nodes and sections (called 'links' in Figure 10), specification of origin and destination nodes, specification of properties of links such as length, capacity etc.
- the position of induction loop sensors
- the position of VMS's (for either lane-usage, speed regulation, dynamic route information, or dynamic route guidance)
- the position of actuators, such as ramp meters, mainline meters and variable speed signs, and lane closure signs

For evaluation purposes it is sufficient to specify the position of induction loops, VMS's and actuators by means of a section descriptor and a longitudinal position across that section. This leads to a hierarchical structure shown in Figure 10:

![Figure 10: Hierarchical Structure of Static Transport Network Data Elements](image-url)
6.2.2. Dynamic data

The dynamic data relate to time-varying characteristics of the transport system such as link-volumes, speeds, settings of ramp-meters, variable message signs, etc.

The dynamic data consist of:

- an estimate of the travel demand (if available)
- a summary of weather conditions
- a summary of incidents, road works, lane closures etc.
- the observations on speed and traffic volumes
- the settings of VMS's
- the settings of ramp meters
- the settings of variable speed signs
- the settings of variable lane closures
- estimates made within the system for:
  - travel time/link
  - traffic volume/link
  - queue lengths

The dynamic data may be linked to the structure shown in Figure 10 (see Figure 11):
6.2.3. Data Collection Cross-Sections, Segments, and Strings

Traffic networks can be modelled as sets of network sections or links, which are connected by means of intersections (or nodes). On various locations on these sections monitoring and actuating devices can be identified.

6.2.3.1. Monitoring Installations

In the evaluation-phase of the DACCORD project, a main source of information will be inductive loops. The data collected by the inductive loops is in general stored and aggregated in distinct time intervals, typically twenty seconds (Paris test-site), or one-minute (Amsterdam, and Padua-Venice networks). Subsequently, these data are collected, cleaned, and stored in the Traffic Control Centres. Consequently, the monitoring process results in time-aggregated measurements of typically twenty seconds or one minute at specific measuring points of the sections of the network.
position data monitoring installations

\[ y_i \quad y_{i+1} \quad \ldots \quad y_{n+1} \]

section under consideration

Figure 12: Monitoring Segments of a Section

The data-collection cross-sections ('base-stations') are located at position \( y_i \) in a so-called monitoring segment of length \( a_i \) (see Figure 12). The length \( a_i \) of a segment is defined as the average of the distances \( d_i \) and \( d_{i+1} \) between the preceding and succeeding locations of the data collection installations. Hence, sections can be seen as sets of monitoring segments which each contain one single data collection point.

This description enables the calculation of indicators of performance at specific points \( y_i \) of the sections, of monitoring segments, and whole sets of monitoring segments, enabling the description of e.g. routes in the segment. In the sequel of this section, both point- and the spatially integrated section-indicators will be identified.

As for the spatial integration, either segments or set of segments called strings will be used as unit for measurements. Note that a segment or string is defined independently of a section.

Furthermore, it is assumed that the output of the base-stations (at least) consist of measured flow-rate and (time-) mean speed at the measuring point.

6.2.3.2. Actuator Installations

Information regarding the control settings of the distinct ATT-applications of control are available in the form of log-files of these control settings. These contain records of the information provided on recommended speed, lane use, route information, or route guidance, and control settings of the separate mainline- or ramp-metering installations.

Just as the monitoring information, this information regarding the control settings are part of the so-called dynamic network description.

6.3. Classification of DACCORD Indicators

6.3.1. Common Indicators and Indicators according to Functions

Figure 13 depicts the organisation of indicators used in this evaluation plan. In general, performance indicators are divided into common indicators, and indicators according to functions.

The term common performance indicators refers to indicators which do not refer to specific functions or strategies. In general, common indicators cover technical assessment, user-acceptance, impact assessment, and economic evaluation. This in
contradiction to the indicators according to the functions, which is general only refer to impact assessment of the specific AIT-application.

![Figure 13: Categories of Indicators and Assessment Categories](image)

### 6.3.1.1. Description Structure for Common Performance Indicators

In this chapter, the common indicators relevant for evaluation phase are described. In this description, the following structure is employed for:

1. the definition of the performance indicator;
2. the relevant assessment category for the common performance indicator considered;
3. the data collection methods employed at both the verification, and demonstration phase of evaluation (if relevant);
4. the scope of the impact, that is the extent of the effects the indicator aims to quantify in spatial terms (point, section, or network level; if relevant).

### 6.3.1.2. Description Structure for Indicators according to Functions

Subsequently, the indicators according to functions will be described. In this description, the following structure is employed for:

1. the definition of the performance indicator;
2. the concept of calculation of the performance indicator, containing among others the equations describing the performance indicator;
3. the type of indicators, that is direct, indirect, or derived;
4. the nature of the impacts the performance indicator aims to quantify, such as effects on the efficiency-level of the transportation network, the safety of the road-users, the environment, and the economy;
5. the scope of the impacts, that is the extent of the effects the indicator aims to quantify in spatial terms (point, section, or network level);
6. the data collection methods employed at both the verification, and demonstration phase of evaluation.

### 6.3.1.3. List of Common Indicators:

The following is a list of both the common indicators, and the indicators according to function, described in the sequel of this chapter.
Common Indicators:
- Cost of Equipment (CE);
- Cost of Operation (CO);
- Information Coverage Ratio (InfoCR);
- Operators' Credibility Factor (OCrF);
- Operators' Comprehensibility (Ocomp);
- Operators' Comfort & Stress-level (OCSL);
- Operator's Utility Rate (OUR);
- Compliance Rate (CR);
- Incident Detection Delay (IDL);
- Congestion Detection Delay (CDL);
- Information Displaying Delay (InfoDL);
- Modification and Cancellation of Information Delay (CInfoDL);
- System's Processing Time (SPT);
- Average Application Failure Time (AFT);
- Accuracy of Output provided by Application (AccO);
- Sensitivity to Inaccurate Input (SensI);

Indicators according to Functions:
- Instantaneous Travel Time (iTT);
- Actual Travel Time (aTT);
- Travel Time Loss (W);
- Cumulative Travel Time Losses (cumW);
- Mean Speed (V);
- Performance (P);
- Traffic Flow Rate (q);
- Speed Variance (sV);
- Hindering Factor (HindF);
- Splitting Proportions at a Diverge (SP);
- Red Light Disobedience factor (RLDf);
- Difference between Mean Speed and Recommended Speed (∆V);
- Lane Usage Ratio (LUR);
- Capacity (C);
- Maximum Performance (MP);
- Total Queue Length (tQL);
- Total Queue Weight (tQW);
- Number of Vehicles (n);
• Congestion Probability ($C_{prob}$);
• Accident Rates ($ArF$, $ArS$, $ArL$);
• Accident Damage ($DamAcc$);
• Fuel Consumption ($FC$);
• Exhaust Gas Emission ($EGE$).

### 6.4. DACCORD Performance Indicators

#### 6.4.1. Description of Common Indicators

**6.4.1.1. Cost of Equipment (CE [ECU])**

**Definition**

The cost of equipment can be divided into the following:

- *investments* in the implemented ATT-application itself, that is the cost of metering installations, VMS panels, cables, monitors, hardware, etc.;
- *share of investment* in equipment for data collection (mainly inductive loops, but also video surveillance, etc.), data storage, and data processing (depending on the level of integration);
- *depreciation* for both the implemented ATT-application, and the equipment for data collection, storage, and processing;
- financial charges derived from both the investment categories.

These cost can be worked out for the **public infrastructure** (network equipment).

**Relevant Category of Assessment**

Economical Evaluation (cost-effectiveness, or cost-benefit analysis)

**Data Collection Methods**

The information of the cost of equipment needs, that is analytical accountancy (charges and revenues) of the ATT-application, is to be provided by the relevant decision-maker, responsible for implementation of the ATT-application (the network-operators).

**6.4.1.2. Cost of Operations (CO [ECU])**

**Definition**

The cost of operation results form the use of the ATT-tool or application under consideration. In agreement to the cost of equipment, both *direct* and *indirect* costs are attributed to the ATT-application. These costs consist of:

- *operational costs*, generated by using the ATT-application (energy consumption, maintenance costs, labour-rates of the operators, etc.);
- *share of operational cost* due to the use of complementary devices, shared by other ATT-applications, such as monitoring devices, data storage and processing facilities.

For the cost estimation the ideal situation is to refer to an analytical accountancy (charges and revenues) of the ATT-application. Subsequently, both the direct and
indirect costs can be worked out by ratios taken into account the configuration of the integrated ATT-applications in DACCORD to calculate the share of operational cost.

**Relevant Category of Assessment**

Economical Evaluation (cost-effectiveness, or cost-benefit analysis)

**Data Collection Methods**

The information of the cost of operations needs to be provided by the relevant decision-maker, responsible for implementation of the ATT-application (the network-operators).

6.4.1.3. Information Coverage Ratio (ICR [-])

The Information Coverage Ratio reflects the extent of the number of drivers which are well covered by the information disseminated by among others the VMS- and VDS-signs. The calculation can be absolute (which drivers should be informed?), or relative to the information strategy of the network operator (what categories of drivers do the system operators choose to inform, and in what context?). These aspects are important since the VMS-systems form a discrete information system, implying that drivers cannot be reached anywhere at any time.

![Figure 14: Example of VMS where ICR=90%](image)

The ICR-indicator integrates the delay for displaying a message and the inertia — the delay experienced due to the fact that when a message is displayed, some drivers are between the panel and the event at the decision point — of the VMS-system.

**Definition**

The ICR is defined by the number of road-users which are 'well covered', and the total number of drivers concerned by an event or the current or predicted conditions of the network, where:

- a well covered driver is defined as a driver, concerned by an event or network conditions, who can be informed or warned in time of the event considered;
- a concerned driver is a driver affected by the event or network conditions (and likely to encounter it);

In these definitions, an event is defined by all elements which may affect the traffic conditions, or otherwise useful for the road-users.

---

9 The Information Coverage Ratio (ICR) has been investigated within USAP and French Road Ministry in 1991. The definition used in the evaluation plan has been derived from this work, see [10].
Relevant Category of Assessment
Technical Assessment

Scope
entire transportation network.

Data Collection Methods
Description of the VMS-dissemination services (static data, and log-files):
- location
- description of the system-operator information strategies
- recordings of VMS-operating times
- log-files of events (location and time of occurrence), and situations
- traffic flows and OD-matrices
- speeds

6.4.1.4. Operators' Credibility Factor (OCrF [-])

Definition
The credibility factor aims to reflect operators' confidence in measurements, estimations, predictions, and other information (remote TCC status, weather conditions). This indicator is especially important in the user-acceptance phase of evaluation, since it directly relates to the likelihood that operators will use the ATT-tools or application.

To this end, operators are inquired about the credibility of the information provided by the ATT-applications, where the credibility is scaled from zero to ten. Presumably, the system operators' confidence in provided estimation, predictions etc., will be based on the results of technical assessment of the ATT-applications considered.

The different ratings are subsequently used to calculate average scores of the different DACCORD ATT-applications.

Relevant Category of Assessment
User-Acceptance Assessment

Scope
entire transportation network.

Data Collection Methods
- interviews with the respective system-operators

6.4.1.5. Operators' Comprehensibility (Ocomp [-])

Definition
Is the information provided by the ATT-application supplied in a clear and unambiguous manner? Can the information be comprehended by the operators?

---

10 The credibility factor proposed in DACCORD relates to the system-operators. Hence, the indicator is not related to the credibility factor mentioned in the EAVES-report.
In order to account for this aspect to user-acceptance with respect to the user-friendliness of the HMI-interfaces, the operators' comprehensibility ($O_{comp}$) is proposed. Operators are asked to rate the comprehensibility of the information provided by the ATT-application on a scale from zero to ten. The different ratings are subsequently used to calculate average scores of the different ATT-applications.

**Relevant Category of Assessment**

User-Acceptance Assessment

**Scope**

entire transportation network.

**Data Collection Methods**

- interviews with the respective system-operators

6.4.1.6. *Operators' Comfort & Stress-level (OCSL [-])*

**Definition**

The operators' comfort & stress level indicates the effect which the ATT-applications results with respect to the comfort and stress experience by the operator.

On the one hand, the *additional assistance* in performing the tasks of the operators, provided by the ATT-application heightens the comfort level. On the other hand, the ATT-application may bestow the operator with additional tasks for operation of the ATT-application.

Analogously to operators' credibility and comprehensibility, the comfort level is assessed by asking the operators about their rating of their comfort level on a scale from zero to ten.

The different ratings are subsequently used to calculate average scores of the different control tools and applications.

**Relevant Category of Assessment**

User-Acceptance Assessment

**Scope**

entire transportation network.

**Data Collection Methods**

- interviews with the respective system-operators

6.4.1.7. *Operator's Utility Rate (OUR [-])*

**Definition**

The operators' utility rate provides insight in the rating of the system operators regarding the overall utility of the applications installed. To this end, the utility rate is assessed by asking the operators about their rating of their comfort level on a scale from zero to ten.
The different ratings are subsequently used to calculate average scores of the different control tools and applications.

**Relevant Category of Assessment**

User-Acceptance Assessment

**Scope**

entire transportation network.

**Data Collection Methods**

- interviews with the respective system-operators

6.4.1.8. Compliance Rate (CR)

The objective of many VMS- and VDS-systems is to alter the behaviour of road-users, i.e. alter the route-choice behaviour, of change driving speeds, lane usage. The effectiveness of the VMS- or VDS-system in achieving this a main factor when assessing the cost-benefit (or cost-effectiveness) of the system.

**Definition**

The compliance rate is the number of drivers complying to the directions or messages on the VMS-sign (e.g. the number of drivers following a route-guidance direction), or to the control policies actuated by the metering installations.

For both route-diversion and lane-usage, the compliance rate involves counts of the number of road-users diverting to the alternative route, or changing lanes. For route diversion, the splitting proportions (SP), which is one of the indicators according to function defined in the sequel, and lane usage ratios (LUR) for lane-usage control.

However, when assessing the effectiveness of route-information, driver (may) react to the differences in the conditions (e.g. travel-times or queue-lengths) of different route-alternatives displayed by the VMS. In this particular case, the compliance rate to the information provided can be seen as a function of the information provided on each route-alternative. The direct effects of information provision by route information can be assessed by analysing splitting proportions (SP) as a function of the provided information.

When assessing speed reduction the element of degree has to be addressed: when asking the road-users to slow down from 100km/h to 50km/h, ninety percent of the road-users may slow down but only by 10km/h. The degree of compliance can then be assessed by comparing the average speed reduction to the required speed reduction. A more complicate value, including the current average speed and its variance would however give a better description of the degree of compliance. However, since individual vehicles speeds are unknown, the speed variance cannot be computed from available data. Hence, compliance rate to speed regulation is only assessed by means of the difference between average speed and recommended speed $AV$. This indicator is defined as a one of the ‘indicators according to functions’ in the sequel of this chapter.

Finally, assessment of compliance rate with respect to metering installations requires analysis of the number of vehicles obeying or disobeying a red light at the metering installations. The respective indicator is the average fraction of vehicles driving through a red-light, divided by the ‘red-time’. This indicator is defined as the red-light disobedience factor ($RLDf$).

**Relevant Category of Assessment**
Impact Assessment (effectiveness of routing-control, lane usage control, and speed regulation control)

**Scope**

Dependent on ATT-application considered (section for lane usage and speed regulation; entire network for routing-control by means of information provision or route-guidance)

**Data Collection Methods**

See splitting proportions at a diverge (SP) for route-information and route-guidance; see difference between average speed and recommended speed (ΔV) for speed-regulation control, and lane usage rates (LUR) for lane-usage control; see red-light disobedience (RLDf) for metering control.

6.4.1.9. *Incident Detection Delay (IDL [hour])*

**Definition**

The incident detection delay refers to two different aspects:

- the alarm itself;
- the validation of the incident.

The delay depends very much on the:

- **type of incident** to be detected:
  - bad weather conditions;
  - congestion beginning and ending;
  - cause of the congestion or the consequence of the incident (the congestion);
  - special events (vehicle stopped);

- **type of technique** used to detect:
  - detection by automatic means (AID software), or manual means (emergency call box system, highway patrol, road-user calling in by mobile phone);
  - detection by forecasting (simulation programmes);
  - quantitative information, qualitative, and video information;

- **type of transmission**:
  - specialised line, or phone line;
  - event-to-event transmission, transmission at regular intervals

The validation is linked to manual and qualitative techniques (often visually determined by for example the system operators at the traffic control centre). An added delay is necessary to separate the cause of the incident from the consequences of the incident.

The incident detection delay corresponds to the delay between the moment an incident occurs and the moment the system operators choose to act and implement a strategy.

**Relevant Category of Assessment**

Technical assessment
**Scope**

The entire network

**Data Collection Methods**

Log-files (either manually or automatically logged)

6.4.1.10. *Congestion Detection Delay (CDL [hour])*

**Definition**

The congestion detection delay refers to two different aspects:

- the congestion alarm itself;
- the validation of congestion.

The delay depends very much on the:

- *location* and *cause* of congestion;
- *type of technique* used to detect:
  - detection by automatic means or manual means;
  - detection by forecasting (simulation programmes);
  - quantitative information, qualitative, and video information;
- *type of transmission*:
  - specialised line, or phone line;
  - event-to-event transmission, transmission at regular intervals

The validation is linked to manual and qualitative techniques (often visually determined by for example the system operators at the traffic control centre).

The congestion detection delay corresponds to the delay between the moment an congestion occurs and the moment the system operators is informed by the system.

**Relevant Category of Assessment**

Technical assessment

**Scope**

The entire network

**Data Collection Methods**

Log-files (either manually or automatically logged)

6.4.1.11. *Information Displaying Delay (InfoDL [hour])*

**Definition**

Four types of delays are distinguished:

1. delay, which due to the *elaboration of the information* depending on:
   - the *complexity* of the information *(InfoDL_I)*:
     - warning, safety advice’s, speed limits, pictograms;
     - information with text;
     - recommendation and route guidance;
on the mechanisms activating the display of information: \((InfoDL_2)\)
- human activation only;
- human supported by written procedural guidelines;
- human helped by decision support software;
- human supported by automatic tools;
- fully autonomous incident management tools

2. delay due to the means of dissemination of information and protocol used \((InfoDL_3)\);

3. delay of displaying the information, dependant on the technology of the VMS- or VDS \((InfoDL_4)\):
- mechanical;
- electrical;

4. delay due to acknowledgement of the message, and validation by the system-operator \((InfoDL_5)\).

The total Information Display Delay corresponds to the sum of these four types of delays, i.e.:

\[
InfoDL = InfoDL_1 + InfoDL_2 + InfoDL_3 + InfoDL_4 + InfoDL_5
\]

**Relevant Category of Assessment**

Technical assessment.

**Scope**

The entire network.

**Data Collection Methods**

Chronological sequences of the operations mentioned above.

6.4.1.12. Modification and Cancellation of Information Delay \((Cl_{infoDL}[hour])\)

The problem of modification of the information causes exactly the same delay as the Information Displaying Delay \((InfoDL)\). However, the cancellation delay does not consider the delay concerning the complexity of the information.

**Definition**

See 6.4.1.11.

\[
CancellationDL = InfoDL_2 + InfoDL_3 + InfoDL_4 + InfoDL_5
\]

\[
ModificationDL = InfoDL_1 + InfoDL_2 + InfoDL_3 + InfoDL_4 + InfoDL_5
\]

**Relevant Category of Assessment**

Technical assessment.

**Scope**

The entire network.

**Data Collection Methods**

Chronological sequences of output provided by the tools and applications (log-files).
6.4.1.13. System Processing Time (SPT)

**Definition**

The systems processing time is defined by the time needed by a specific (sub-) system to perform its task. In general, the processing time can be divided into processing times of subsystems of the main system and the delay due to transmission of data between these respective subsystems.

**Relevant Category of Assessment**

Technical assessment.

**Scope**

The entire network.

**Data Collection Methods**

Chronological sequences of output provided by the tools and applications in DACCORD (log-files).

6.4.1.14. Average Application Failure Time (AFT \([\cdot]\))

**Definition**

The average application failure time is defined by the proportion of time at the study period the ATT-application has been out of order. In general, failure of an application may be caused by:

- technical failure of the main application itself \((FT_{main})\);
- failure of the \(i\)-th key-subsystem on which the ATT-application depends, for example due to input-provision, at the data collection, data storage, or processing level \((FT_{sub\_i})\);
- failure of infrastructure providing means for data transportation between main application and sub-applications \((FT_{infr\_i})\).

Moreover, the application failure times of the subsystems providing input may on their part be dependent on the failure times of other subsystems.

**Relevant Category of Assessment**

Technical assessment.

**Scope**

The entire network.

**Data Collection Methods**

Chronological sequences of output provided by the ATT-applications in DACCORD (log-files), and realised traffic counts and vehicles speeds providing means for comparison:

6.4.1.15. Accuracy of provided Output (AccO)

**Definition**

The Accuracy of provided Output is defined by the relative error made by the data collection, data cleaning, section- or network-state estimation, and prediction systems, with respect to faultless measurements, or estimations and predictions.
which are significantly more accurate. For the different DACCORD tools, accuracy is defined differently:

- At the *data collection level*, the accuracy of the application is defined by the relative error in the collected data. It can be determined by comparison to more accurate information sources, or cleaned measurements;

- at the *data cleaning stage*, the accuracy of the application is defined by the relative error in the cleaned data with respect to other (more accurate) information, e.g. traffic state estimations (comparing the output provided by the data cleaning applications to data at a higher level of the functional architecture, e.g. the estimations provided by the estimation level);

- at the *state-estimation level*, the accuracy can be estimated by studying various 'residual output' from the estimation procedures. For example, using Kalman filtering techniques results in estimates for the relative error of the estimation calculated;

- at the *prediction level*, the accuracy can be calculated by comparison between the logged predicted traffic-states, and the realised traffic states.

**Relevant Category of Assessment**

Technical assessment.

**Scope**

The entire network.

**Data Collection Methods**

- for the *data collection level*, use will be made of the expertise of the system-operators (interviews with operators). Additionally, results from previous technical assessment studies will be used;

- for the *data cleaning stage*, the cleaned data is collected and stored. Additionally, the expertise of the system-operators is used by means of interviews. Additionally, results from previous technical assessment studies will be used;

- for the *state-estimation level*, storage of 'residual output' of the estimation procedures;

- for the *prediction level*, logged predicted traffic states, and stored realised traffic states.
6.4.1.16. Sensitivity to Inaccurate Input (SensI [-])

**Definition**

The sensitivity to inaccurate output is defined by the susceptibility of the ATT-application to erroneous input provided by subsystems, i.e. the (relative) changes in the output of an ATT-application with respect to (relative) changes in the input provided by the various subsystems.

![Diagram of ATT-Application](image)

*Figure 15: Sensitivity of ATT-Application*

Hence, the following equation can be used:

\[
SensI = \frac{\delta e_{output}}{\delta e_{input}}
\]

where \( \delta e_{output} \) and \( \delta e_{input} \) are defined as the relative change in the input and output of the system, i.e.:

\[
\delta e_{input/output} = \frac{e_{input/output}}{x_{input/output}}
\]

where \( x_{input/output} \) denote the input and output of the system respectively.

The extent of the degradation in performance due to the inaccuracies to which the application is susceptible can be expressed by different indicators of performance (depending on which ATT-applications is being assessed).

For example, if the sensitivity of a tool for the estimation of travel times is assessed, the input of the system would be cleaned traffic counts and speed samples. If small perturbations are introduced, perturbations in the estimated travel times result. The sensitivity of the travel time estimation algorithm can subsequently be determined.

**Relevant Category of Assessment**

Technical assessment.

**Scope**

The entire network.

**Data Collection Methods**

The requirements on the data collected for quantifying this indicator is to a large extent dependent on the ATT-application being assessed:

- **at the data cleaning stage**, the sensitivity of the application is defined by the changes in the output of the data cleaning systems due to changes in data provided to these systems (missing data and false data). Comparisons are drawn either by editing or simulating the data provided by the inductive loops (removing data, or inserting false data), or by comparing the output provided
by the data cleaning applications to data at a higher level of the functional architecture, e.g. the estimations provided by the estimation level;

- at the state-estimation level, the sensitivity is calculated by varying the input (cleaned data from among others the data cleaning subsystems, from other estimation-applications, data from weather forecast bureau's, data from remote Traffic Control Centres), and determining the relative change in the output of the state-estimation at the different estimation level (section, or traffic state estimation)

- at the control level, the sensitivity is addressed by assessment of changes in the output of the control-systems by varying the input of the subsystems (primarily state estimation, weather forecasts, remote traffic state). In DACCORD, the sensitivity of the control systems can only be assessed in a simulated environment (verification stage).

6.4.2. Description of Indicators according to Functions

As mentioned before, the indicators according to the functions reflect the impacts of the ATT-applications on the efficiency or provided level of service, safety, and environment of the transportation network. The indicators of performance provide either direct information with these impact, or are used as an input for more complicated impact analysis techniques, such as regression analysis, stimuli-response analysis, filtering techniques, etc. For these techniques, additional information regarding for example weather conditions, remote TCC-application settings, current and predicted control settings are necessary. This information will be derived from log-files of the traffic control centres.

For the calculation of the indicators it is assumed that twenty-seconds or one-minute aggregate time series of the flow-rate $q_i$ and the time-mean speed $v_i$ at the measuring points $i$ are available, either from simulation-results (at the verification stage), or from (cleaned) real-life measurements (at both the verification and demonstration stage). Additionally, the lengths $a_i$ of the segments $i$ relating to the different base-stations are known.

6.4.2.1. Instantaneous Travel Time ($iTT$ [hour])

Definition

The instantaneous travel time is defined as the travel time a road-user would experience if the current traffic conditions with respect to time-mean speeds at the different base-stations (not the average traffic flows) prevail for the entire time needed to traverse the considered string of segments. Clearly, the instantaneous travel time rarely equals the actual travel time experienced by the road-users, unless traffic conditions on the transportation network are unconstrained.

Concept of Calculation

Instantaneous travel time at period $t$ is defined both for a segment $i$, and for an entire string of segments, as follows:

$$iTT_i(t) = \frac{a_i}{v_i(t)}$$

For a string of segments $S = \{1, \ldots, N\}$ the following definition can be applied:

$$iTT_S(t) = \sum_{i=1}^{N} iTT_i(t)$$
Type of Indicator
Indirect

Nature of Impacts
Provided level of service

Scope of Impacts
Entire transportation network

Data Collection Methods

Simulation [verification stage]: data collection of speeds \( v_i \) at various points at different simulated measuring points. The measurements are aggregated into periods \( k \) of length \( \Delta \) (typically five or fifteen minutes), enabling calculation of the \( iTT(k) \).

Real-Life Measurements [verification, and demonstration stage]: data collection of speeds \( v_i \) at the distinct measuring points \( i \), and aggregated in time intervals \( t \) of length \( T \) (typically twenty seconds or one-minute intervals). These measurements are aggregated further into periods \( k \) of length \( \Delta \), such that \( \Delta T = M \) (typically five or fifteen minutes), enabling calculation of the \( iTT(k) \), by weighting with the number of vehicles which have passed the section, and the number of measuring periods \( t \) with correct data:

\[
iTT_i(k) = \frac{\sum_{t=1}^{M-1} m_i(t) \cdot ok_i(t)}{\sum_{t=1}^{M-1} m_i(t) \cdot ok_i(t)} \cdot iTT_i(t) \cdot \Delta T \cdot \Delta \]

where \( m_i(t) \) denotes the number of vehicles which have passed the measuring cross-section \( i \) during-time-period \( t \), and \( ok_i(t) \) denotes whether the data at measuring cross-section \( i \) was either correct (\( ok_i(t) = 1 \)), or missing (\( ok_i(t) = 0 \)).

6.4.2.2. Actual Travel Time (\( aTT \) [hour])

Definition
The actual travel time of a string \( S \) of segments \( i \) is defined as the actual (average) travel time the road-users have experienced when traversing \( S \).

Concept of Calculation
Although the calculation of the actual travel time is slightly more complicated from the instantaneous travel time, it can be realised from ex-post analysis of average speed measurements at the different base-stations \( i \) of string \( S \). The actual travel time of a segment \( i \) is identical to the instantaneous travel time \( iTT_i(t) \). The actual travel time of string \( S = \{1,\ldots,N\} \) can be approximated as follows:

\[
\Delta aTT_i(t) = iTT_i(t + \Delta aTT_{i-1}(t)) + \Delta aTT_{i-1}(t), \quad \text{for } i = 1,\ldots,N
\]

\[
aTT_S(t) = \Delta aTT_N(t)
\]

Typically, the value of \( \Delta aTT_i(t) \) will be in-between the periods. In this case, simple linear interpolation is used to define the instantaneous travel time:

\[
iTT_i(t + \beta) = \alpha \cdot iTT_i(t + \lfloor \beta \rfloor) + (1 - \alpha) \cdot iTT_i(t + \lfloor \beta \rfloor + 1),
\]

where \( \lfloor \beta \rfloor \) denotes the biggest integer value smaller than \( \beta \), and

\[
\alpha = \lfloor \beta \rfloor - \beta + 1
\]

Type of Indicator
Indirect

Nature of Impacts

Provided level of service

Scope of Impacts

Entire transportation network

Data Collection Methods

See 6.4.2.1.

6.4.2.3. Travel Time Loss (\(W_{\text{hour}}\))

Definition

The travel time loss is defined as the excess instantaneous travel time needed to traverse the string \(S\), if compared to free-flow traffic conditions.

Concept of Calculation

The travel time loss \(W_i(t)\) at segment \(i\) at period \(t\) is defined as:

\[
W_i(t) = \max \left\{ iTT_i(t) - \frac{a_i}{v_i(t)}, 0 \right\}
\]

where \(v_i(t)\) is the average travel time under free-flow conditions at the section under consideration.

The travel time loss for a string \(S\) can be calculated simply by addition of the travel time losses of each segment \(i\):

\[
W_S(t) = \sum_{i=1}^{N} W_i(t)
\]

Type of Indicator

Indirect

Nature of Impacts

Provided level of service

Scope of Impacts

Entire transportation network

Data Collection Methods

See 6.4.2.1.

6.4.2.4. Cumulative Travel Time Losses (\(\text{cum} W_{\text{veh hour}}\))

Definition

The cumulative travel time losses are simply the total travel time losses of the collective of road-users traversing the segment or string.

Concept of Calculation

The cumulative travel time loss of a segment \(i\) is equal to:

\[
\text{cum} W_i(t) = n_i(t) \cdot W_i(t)
\]

where \(n_i(t)\) denotes the number of vehicles which have passed the measuring cross-section \(i\) during time-period \(t\).
The cumulative travel time loss of a string \( S = \{1, \ldots, N\} \) equals:

\[
cum W_S(t) = \sum_{i=1}^{N} m_i(t) \cdot W_i(t)
\]

**Type of Indicator**
Indirect

**Nature of Impacts**
Provided level of service

**Scope of Impacts**
Entire transportation network

**Data Collection Methods**
See 6.4.2.1.

6.4.2.5. **Mean Speed \((V [\text{km/hour}])\)**

**Definition**

The mean speed \( v_i(t) \) is the average speed of measurement location \( i \) at interval \( t \) is a direct output of the data collection and data cleaning systems. The average speed of a string is defined as the length of the string divided by the instantaneous travel time.

**Concept of Calculation**

The mean speed experienced at a string \( S \) is defined as:

\[
v_S(t) = \frac{\sum_{i=1}^{N} a_i}{\text{iTT}_S(t)}
\]

**Type of Indicator**
At a segment: direct; at a string: indirect.

**Nature of Impacts**
Provided level of service

**Scope of Impacts**
Entire transportation network

**Data Collection Methods**
See 6.4.2.1.

6.4.2.6. **Performance \((P \text{ [veh km]}\))**

**Definition**

The performance \( P_i(t) \) of a segment \( i \) or a string \( S \) is defined as the flow-rate at the segments, multiplied by the length of the segments. The performance 'generalises' flow-rate by elevation the effects of unequally spaced measuring points.

**Concept of Calculation**

The performance \( P_i(t) \) of segment \( i \) at time \( t \) can be calculated using the following equation:

\[
P_i(t) = q_i(t) \cdot a_i \cdot \Delta
\]
where \( \Delta \) denotes the period length.

The performance \( P_s(t) \) of a string \( S \) at time \( t \) can be calculated from the performances of the segments \( i \) part of the string:

\[
P_s(t) = \sum_{i=1}^{N} P_i(t)
\]

**Type of Indicator**

At a segment: direct; at a string: indirect.

**Nature of Impacts**

Provided level of service

**Scope of Impacts**

Entire transportation network

**Data Collection Methods**

*Simulation* [verification stage]: data collection of flow-rates \( q_i \) at various point at different simulated measuring points. The measurements are aggregated into periods \( t \) of length \( \Delta \) (typically five or fifteen minutes).

*Real-Life Measurements* [verification, and demonstration stage]: data of flow-rates \( q_i \) collection at the distinct measuring points \( i \), and aggregated in time intervals \( t \) of length \( T \) (typically twenty seconds or one-minute intervals). These measurements are aggregated further into periods \( k \) of length \( \Delta \), such that \( \Delta T = M \) (typically five of fifteen minutes), corrected for the number of periods \( t \) with missing data.

6.4.2.7. Traffic Flow Rate (\( q \) [veh/hour])

**Definition**

The flow-rate \( q_i(t) \) is defined as the average number of vehicles per hour passing the measuring point \( i \) at time \( t \), or the performance \( P_i(t) \) of segment \( i \), divided by the length of segment \( i \). The flow-rate \( q_S(t) \) of the string \( S \) at time \( t \) is defined analogously: the performance of the string divided by the total length of the string.

**Concept of Calculation**

The flow-rate at segment \( i \) is collected directly from the base-stations \( i \) (additional averaging over time may be performed).

The flow-rate of a string \( S \) can be calculated by using the following equation:

\[
q_S(t) = \frac{\sum_{i=1}^{N} q_i(t) \cdot a_i}{\sum_{i=1}^{N} a_i} = \frac{P_S(t)}{\Delta \cdot a_S}
\]

**Type of Indicator**

At a segment: direct; at a string: indirect.

**Nature of Impacts**

Provided level of service

**Scope of Impacts**

Entire transportation network
Data Collection Methods

See 6.4.2.6.

6.4.2.8. Speed Variance ($sV$ [km²/hour²])

Definition

The speed variance is defined as the squared differences between the speeds of mean speeds aggregated for time periods of length $T$ and the mean speed during a moving interval of length $\Delta$, defined by $[t-0.5\Delta, t+0.5\Delta]$.

Concept of Calculation

For the speed variance $sV_i(t)$ at time $t$, at a measuring point $i$, the following equation holds:

$$sV_i(t) = \frac{1}{M-1} \sum_{k=1}^{[M/2]-1} \left( V_{i,\text{ma}}^k(t) - v_i(t) \right)$$

where $V_{i,\text{ma}}^k(t)$ denotes the moving average speed at location $i$ for the identified interval, and $v_i(t)$ the measured average speed at time $t$ and location $i$.

Aggregation of the speed variance to a string of segments is less straightforward. In order to find an 'average speed variance' of the segment, both the lengths and the flow-rates need to be incorporated, resulting in the following expression:

$$sV_s(t) = \frac{\sum_{i=1}^{N} P_i(t) \cdot sV_i(t)}{\sum_{i=1}^{N} P_i(t)}$$

Type of Indicator

Indirect

Nature of Impacts

Safety

Scope of Impacts

Entire transportation network.

Data Collection Methods

See 6.4.2.6.

6.4.2.9. Hindering Factor ($\text{HindF}_i$)

Definition

The hindering factor is a function which describes the difference between the speed under ideal conditions $\nu^i$, the current speed $V(t)$, and the current speed variance $sV(t)$ at a time $t$.

The indicator is used to assess both safety and driver stress. The value of the hindering factor varies between zero (no 'hindering') and one (major 'hindering').

Concept of Calculation

The hindering factor $\text{HindF}_i(t)$ at time $t$ at a measuring point $i$, is determined using the following equation:
Aggregation of the hindering factor to a string of segments is less straightforward. In order to find an 'average speed variance' of the segment, both the lengths and the flow-rates need to be incorporated, resulting in the following expression:

\[ \text{HindF}_s(t) = \frac{\sum_{i=1}^{N} P_i(t) \cdot \text{HindF}_i(t)}{\sum_{i=1}^{N} P_i(t)} \]

**Type of Indicator**
Indirect

**Nature of Impacts**
Safety

**Scope of Impacts**
Entire transportation network.

**Data Collection Methods**
See 6.4.2.6.

**6.4.2.10. Splitting Proportions at a Diverge (SP [-])**

**Definition**
The splitting proportions at a diverge are defined as the proportion of traffic flow choosing one of the route alternatives with respect to the total flow of vehicles choosing either route.

**Concept of Calculation**
The splitting proportions at a diverge can be calculated by measuring the flow-rate \( q_i(t) \) at two well chosen measuring points: one just before the diverge, and the other just after, or two measuring points just after the diverge.

In the one-before and one-after case, the following equation can be used:

\[ \text{SP}_i(t) = \frac{q_{\text{after}}(t)}{q_{\text{before}}(t)} \]

When the two measuring points are chosen after the bifurcation point, the following formula can be used:

\[ \text{SP}_i(t) = \frac{q_{\text{before,1}}(t)}{q_{\text{before,1}}(t) + q_{\text{before,2}}(t)} \]

**Type of Indicator**
Indirect

**Nature of Impacts**
Impact on route choice behaviour (direct); impact on level of service (indirect).

**Scope of Impacts**
Bifurcation points; entire transportation network.
Data Collection Methods

Simulation [verification stage]: data collection of flow-rates $q_i$ at various point at different simulated measuring points. The measurements are aggregated into periods $t$ of length $\Delta$ (typically five or fifteen minutes).

Real-Life Measurements [verification, and demonstration stage]: data of flow-rates $q_i$ collection at the distinct measuring points $i$, and aggregated in time intervals $t$ of length $T$ (typically twenty seconds or one-minute intervals). These measurements are aggregated further into periods $k$ of length $\Delta$, such that $\Delta/T=M$ (typically five of fifteen minutes). Care should be taken that the selected measuring points are able to measure all relevant traffic flows (see Figure 16). Additionally, the distance between the measuring points should be as small as possible.

![Figure 16: Situation where OS_2 and OS_3 should be chosen](image)

6.4.2.11 Difference between Mean Speed and Recommended Speed ($\Delta V \text{ [km/hour]}$)

Definition

The indicator $\Delta V$ is defined by the difference between mean speed and recommended speed on a segment within a certain time interval. The performance indicator is useful for determining the compliance of road-users to speed recommendations provided by VMS-signs.

Concept of Calculation

The difference between mean- and recommended speed at a measuring point $i$ is defined as:

$$\Delta v_i(t) = v_i(t) - v_i^*(t)$$

where $v_i^*(t)$ denotes the recommended speed at measuring point $i$ at time $t$.

The difference between mean- and recommended speed at a measuring point $i$ is defined as:

$$\Delta v_g(t) = v_g(t) - v_g^*(t)$$

Type of Indicator

Direct.

Nature of Impacts

Compliance rate of road-users to speed recommendation section-control.

Scope of Impacts

Entire transportation network
Data Collection Methods
See 6.4.2.1.

6.4.2.12. Red Light Disobedience rate (RLDf [veh/hour])

Definition:
the Red Light Disobedience rate is defined as the average number of vehicles which are not complying to the red-light at either a ramp-metering, or a mainline-metering installation.

The indicator is defined at a point. No consistent definitions for segment, or strings can be formulated.

Concept of Calculation
The Red Light Disobedience rate at time interval \( k \) is defined by the number of vehicles \( m_r(k) \) which haven’t complied to the red-light at the ramp- or mainline-metering installation in interval \( k \), divided by the total red-time \( T_r(k) \) at time interval \( k \).

\[
RLDf(k) = \frac{m_r(k)}{T_r(k)}
\]

Type of Indicator
Direct.

Nature of Impacts
Compliance rate of road-users.

Scope of Impacts
Points (intersections) in the transportation network

Data Collection Concepts:
Real-Life Measurements [verification, and demonstration stage]: automatic data collection of red-light violations by ramp metering installation’s measurement system, or integrated data collection system. Log files of metering cycle times

6.4.2.13. Lane Usage Ratio (LUR [-])

Definition
The lane usage ratio is defined as the fraction of flow on a measuring point \( i \) using a pre-defined lane \( A \), or set of lanes.

Concept of Calculation
The lane usage ratio \( LUR_i(t) \) can be calculated using the following equation:

\[
LUR_i(t) = \frac{q_{i\cdot A}(t)}{q_i(t)}
\]

where \( q_{i\cdot A}(t) \) denotes the flow-rate at \( t \) at measuring point \( i \) employing the (set of) lane \( A \) (see Figure 17).
Figure 17: Lane Usage Ratio

Type of Indicator
Direct.

Nature of Impacts
Compliance rate of road-users to lane usage control.

Scope of Impacts
Entire transportation network

Data Collection Methods
See 6.4.2.6.

Additionally, the data from the measuring points should be dis-aggregate for the relevant sets of lanes.

6.4.2.14. Capacity (C [veh/hour])

Definition
The capacity $c_i(t)$ of a facility at a measuring point $i$ is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse through a point or a uniform section of a lane or roadway during a given time period under prevailing, traffic, and control conditions.

Concept of Calculation
The capacity has to be calculated from hourly flow rates. If sufficient volume data are available, survival analysis is the most appropriate way to calculate capacity. A commonly used method is the product-limit method. Alternatively, other estimation of the capacity can be used, e.g. the on-line estimation method proposed in [9].

Type of Indicator
Derived.

Nature of Impacts
Impact on level of service.

Scope of Impacts
Entire transportation network

Data Collection Methods
See 6.4.2.6.
6.4.2.15 Maximum Performance (MP [veh km])

Definition

The maximum performance of a segment \( i \) or a string \( S \) is defined as the capacity at the segments, multiplied by the length of the segments. The maximum performance 'generalises' capacity by elevation the effects of unequally spaced measuring points.

Concept of Calculation

The performance \( MP_i(t) \) [veh km/s] of segment \( i \) at time \( t \) can be calculated using the following equation:

\[
MP_i(t) = c_i(t) \cdot a_i \cdot \Delta
\]

The performance \( P_S(t) \) of a string \( S \) at time \( t \) can be calculated from the performances of the segments \( i \) part of the string:

\[
P_S(t) = \sum_{i=1}^{N} MP_i(t)
\]

Type of Indicator

At a segment: direct; at a string: indirect.

Nature of Impacts

Provided level of service

Scope of Impacts

Entire transportation network

Data Collection Methods

See 6.4.2.14

6.4.2.16 Total Queue Length (tQL [queue-km])

Definition

The queue length at a segment \( i \) is defined as the length of the segment if congestion is experiences by the road-users on the segment. Consequently, the total queue length on a string \( S \) is the sum of queue lengths of the segments \( i \).

Concept of Calculation

The queue length at a segment \( i \) is defined by the following equation:

\[
tQL_i(t) = \begin{cases} 
0, & \text{if } v_i(t) \geq v_{congestion} \\
\frac{a_i}{\Delta}, & \text{elsewhere}
\end{cases}
\]

Herein, \( v_{congestion} \) is the threshold for the average speed at which congestion is imminent (typically 50km/hr).

Hence, for a string \( S=\{1,2,\ldots,N\} \), we have:

\[
tQL_S(t) = \sum_{i=1}^{N} tQL_i(t)
\]

Type of Indicator

Indirect.
Nature of Impacts
Level of service.

Scope of Impacts
Entire transportation network

Data Collection Methods
See 6.4.2.1.

6.4.2.17. Total Queue Weight (tQW [queue-lane-km])

Definition
The queue weight at a segment $i$ is defined as the length of the segment multiplied by the number of lanes $s_i$, if congestion is experienced by the road-users on the segment. Consequently, the total queue weight on a string $S$ is the sum of queue lengths of the segments $i$.

Clearly, since in the queue-weight the number of lanes (the 'width' of the congestion) is quantified, the level of congestion at different segment or strings can be compared more efficiently.

Concept of Calculation
The queue length at a segment $i$ is defined by the following equation:

$$tQW_i(t) = \begin{cases} 0, & \text{if } v_i(t) \geq v_{\text{congestion}} \\ a_i \cdot s_i, & \text{elsewhere} \end{cases}$$

Hence, for a string $S = \{1, 2, ..., N\}$, we have:

$$tQW_S(t) = \sum_{i=1}^{N} tQW_i(t)$$

Type of Indicator
Indirect.

Nature of Impacts
Level of service.

Scope of Impacts
Entire transportation network.

Data Collection Methods
See 6.4.2.1.

6.4.2.18. Number of Vehicles (n [veh])

Definition
The number of vehicles at a segment $i$ is defined by the flow $q_i(t)$ through a segment, multiplied by the average speed of this section $v_i(t)$. The total number of vehicles on a string $S$ can consequently be defined as the sum of the vehicles on each segment $i$ of the string.

Concept of Calculation
The number of vehicles can be calculated using the following equation:
\[ n_i(t) = \frac{q_i(t)}{v_i(t)} \]

**Type of Indicator**
Indirect.

**Nature of Impacts**
Level of service.

**Scope of Impacts**
Entire transportation network.

**Data Collection Methods**
See 6.4.2.1.

6.4.2.19. *Congestion Probability (Cprob*)

**Definition**
The congestion probability \( Cprob_i(t) \) at a segment \( i \) is defined by the frequency of congestion at the segment at a time interval \( t \), experienced during the study period.

The congestion probability \( Cprob_S(t) \) at a string \( S \) is defined by the frequency congestion is experienced somewhere on the string \( S \).

**Concept of Calculation**
The following equation is used to determine the congestion probability at a segment:

\[
Cprob_i(t) = \frac{\text{number of days } d \text{ for which } tQL_i(t;d) > 0}{\text{number of days in study period}}
\]

Analogously, for a string \( S \) we have:

\[
Cprob_S(t) = \frac{\text{number of days } d \text{ for which } tQL_S(t;d) > 0}{\text{number of days in study period}}
\]

**Type of Indicator**
Indirect.

**Nature of Impacts**
Level of service.

**Scope of Impacts**
Entire transportation network.

**Data Collection Methods**
See 6.4.2.1.

\[ \text{The congestion probability is explicitly defined as an indicator, providing means to assess the reliability of the transportation network. However, analogously other measures can be proposed for reliability assessment (e.g. variances in travel times, and queue lengths). Such quantities are derived in the chapter on assessment tools.} \]
6.4.2.20 Accident Rate (\(ArF, ArS, ArL\ [acc/10^6km]\))

**Definition**

The ratio of the number of accidents and vehicle mileage with a certain time interval related to the carriageway.

This is a basic indicator for the assessment of the safety of roads. With respect to socio-economic evaluation, it is subdivided further into number of *fatalities* (\(ArF\)), *severely injured* (\(ArS\)), and *lightly injured* (\(ArL\)).

**Concept of Calculation**

The following equations define the different types of accident rates:

\[
ArF = \frac{N_F}{L},
\]

\[
ArS = \frac{N_S}{L},\text{ and}
\]

\[
ArL = \frac{N_L}{L},
\]

where \(N_F\), \(N_S\), and \(N_L\) denote the number of fatalities, severely injured, and (slightly) lightly injured persons, and \(L\) denotes the vehicle mileage (in \(10^6km\)).

**Type of Indicator**

Direct.

**Nature of Impacts**

Safety.

**Scope of Impacts**

Entire transportation network.

**Data Collection Methods**

Accident records of the police or of the road authorities.

6.4.2.21 Damage resulting from Accidents (\(\text{DamAc [ECU]}\))

**Definition**

The damage resulting from accidents comprises all *material* damage *directly* induced by an accident. Hence, indirect damage, for example costs due to increased travel time losses, are not accounted for.

**Type of Indicator**

Direct.

**Nature of Impacts**

Economic Assessment.

**Scope of Impacts**

Entire transportation network.

**Data Collection Methods**

Accident records of the police or of the road authorities.
6.4.2.22. Fuel Consumption (FC [litr])

**Definition**

Fuel consumption by vehicles due to traversing specific segments \( i \), or strings \( S \).

Ideally, fuel consumption is determined in dependence of the type of engine (petrol engine, diesel engine), the current mean speed \( v_i(t) \), and the longitudinal gradient. This necessitates the availability of estimates regarding the composition of traffic demand with respect to the percentage of trucks. The influence of the longitudinal gradient is expected to be very small, and shall consequently be neglected. Additionally, due to restriction on the available data in DACCORD, the average speed of both passenger cars, and trucks is assumed equal.

**Concept of Calculation**

The total fuel consumption on a segment \( i \) within a period \( t \) is calculated using the following formula:

\[
FC_i(t) = \frac{FC_{ct}(t) + FC_{at}(t)}{2}
\]

where \( FC_{ct}(t) \), and \( FC_{at}(t) \) denote the fuel consumption with respect to travel time and travelled distance respectively. Herein, we have:

\[
FC_{ct}(t) = \left( \alpha(t) \cdot FCP_{ct}(v_i(t)) + (1 - \alpha(t)) \cdot FCT_{ct}(v_i(t)) \right) \cdot \frac{P_i(t)}{v_i(t)}
\]

\[
FC_{at}(t) = \left( \alpha(t) \cdot FCP_{at}(v_i(t)) + (1 - \alpha(t)) \cdot FCT_{at}(v_i(t)) \right) \cdot P_i(t)
\]

where \( \alpha(t) \) is an estimate for the percentage of passenger-cars, \( FCP_{ct} \), and \( FCT_{ct} \) respectively denote the fuel consumption functions of a single passenger car, and a single truck driving at a given average speed, with regard to travel time (for example, see [15]), and \( FCP_{at} \) and \( FCT_{at} \) respectively denote the fuel consumption of a single passenger car, and a single truck driving at a given average speed, with regard to travelled distance (for example, see [15]).

The total fuel consumption on a string \( S \) within a period \( t \) is calculated by adding the fuel consumption on the segments \( i \):

\[
FC_S(t) = \sum_{i=1}^{N} FC_i(t)
\]

**Type of Indicator**

Indirect.

**Nature of Impacts**

Socio-Economic evaluation.

**Scope of Impacts**

Entire transportation network.

**Data Collection Methods**

See 6.4.2.6.
6.4.2.23. Exhaust Gas Emission (EGE [gr/km])

Definition

Exhaust Gas Emissions denote the level of emissions of CO, HC, NOx, SO2, and CO2 in gr./km, taking into account the percentage of trucks, and the mean speed at a segment or a string of segments.

Concept of Calculation

Either country specific functions, utilising mean speed, and percentage of trucks, can be used to determine the exhaust gas emission, or particular German studies (see [15]) can be applied.

Type of Indicator

Indirect.

Nature of Impacts

Socio-Economic evaluation.

Scope of Impacts

Entire transportation network

Data Collection Methods

See 6.4.2.6.

6.5. Performance Indicators for Integrated ATT-Systems

In the last part of this section concerning performance indicators, the measures of effectiveness to enable assessment of integration of tools and ATT-applications are proposed.

Again, a distinction is made between common indicators, and indicators according to functions:

Common Indicators:

- Extent of Integration of Data Sources (IntDS);
- Extent of Integration of Data Acquisition and Storage Facilities (IntDB);
- Extent of Integration at Data Processing Level (IntDP);
- Extent of Integration at the Central Control level (IntCC);
- Extent of Integration at Message Diffusion Level (IntMD);
- Relevant common indicators for individual tools and applications.

Indicators according to Functions:

- Relevant common indicators for individual tools and applications.

In the sequel, a description of the indicators specifically designed or re-defined for the assessment of integration are described.
6.5.1.1. Extent of Integration of Data Sources (IntDS)

Definition

This indicator is defined by the number of shared sources of information, compared by the total number of sources available to all subsystems. Additionally, the different sources are weighted depending on their criticality with respect to the 'choice' for a primary information source by the individual applications.

Concept of Calculation

Let $Data_{App_j}$ indicate the distinct information sources present for all ATT-applications in DACCORD, e.g.:
- inductive loops of the VMS-, or the VDS-systems;
- the local induction loops of the isolated ramp metering systems;
- CCTV in tunnels for incident detection;
- weather-status sensors.

Let $DS_k$ denote the set of data sources $Data_{App_j}$ with $j$ in $DS_k$ used by application $k$. Then, the Extent of Integration of Data Sources of a (sub-) set of applications $K'$ is defined by:

$$IntDS = \frac{|\bigcap_{k \in K'} \left( \bigcup_{j \in DS_k} Data_{App_j} \right)|}{|\bigcup_{k \in K'} \left( \bigcup_{j \in DS_k} Data_{App_j} \right)|}$$

where $|S|$ denotes the number of elements in $S$ (see figure).

$|S| = DACCORD$ data source

Figure 18: Sets of Data Sources and Common Data Sources

Relevant Category of Assessment

Technical assessment

Scope

The entire network
**Data Collection Methods**

Examination of the functional specifications of the different ATT-applications (see [14]) providing an analysis of the potential of integration at the data source level. *A posteriori* (examining which data sources are used to what extent in operation, e.g. by studying the log-books).

6.5.1.2. Extent of Integration of Data Acquisition and Storage Facilities (IntDB)

**Definition**

The extent of integration of data acquisition and storage facilities is defined by the proportion of data provided by common acquisition and storage facilities, provided and used by different DACCORD ATT-applications. As for the extent of integration of data sources, data is weighted according to their criticality.

The aim of the indicator is to represent the integration of data acquisition and storage, thereby expressing the coherence and the robustness of system operation.

**Concept of Calculation**

Let \( Data_{App} \) indicate the distinct data acquisition and data storage present for all ATT-applications in DACCORD, e.g.:

- applications for the acquirement of raw TRAC data;
- historical data-base of cleaned TRAC data;

Let \( DS_f \) denote the set of data acquisition and data storage applications \( Data_{App} \), with \( j \) in \( DS_f \) used by application \( k \). Then, the Extent of Integration of Data Acquisition and Storage Facilities of a (sub-) set of applications \( K^* \) is defined by:

\[
IntDB = \frac{\bigcap_{k \in K^*} \bigcup_{j \in DS_f} Data_{App_j}}{\bigcup_{k \in K^*} \bigcup_{j \in DS_f} Data_{App_j}}
\]

where \( |S| \) denotes the number of elements in \( S \).

**Relevant Category of Assessment**

Technical assessment

**Scope**

The entire network

**Data Collection Methods**

Examination of the functional specifications of the different ATT-applications (see [13]) providing *a priori* analysis of the potential of integration at the data acquisition and storage level. *A posteriori* (examining which data acquisition and storage facilities are used to what extent in real-life operation, e.g. by studying the log-books).

6.5.1.3. Extent of Integration at Data Processing Level (IntDP)

**Definition**

The extent of integration at data procession level is defined by the proportion of data which is provided by the same data processing facilities to distinct ATT-applications. These data are weighted according to their significance for the different ATT-applications.
The aim of this indicator is to represent the level of integration at the data processing level. Again, the indicator reflects the coherence and robustness of the system operation.

Concept of Calculation

Let $\text{Data}_j$ indicate the distinct amount of data present for all ATT-applications in DACCORD, provided by data processing facility $j$, e.g.:
- data cleaning subsystems;
- state estimation subsystems.

Let $DS_k$ denote the set of data processing facilities $j$, with $j$ in $DS_k$ used by application $k$. Then, the Extent of Integration of Data Acquisition and Storage Facilities of a (sub-) set of applications $K'$ is defined by:

$$\text{Int}_{DB} = \frac{\left| \bigcap_{k \in K'} \left( \bigcup_{j \in DS_k} \text{Data}_j \right) \right|}{\left| \bigcup_{k \in K'} \left( \bigcup_{j \in DS_k} \text{Data}_j \right) \right|}$$

where $|S|$ denotes the number of elements in $S$.

Relevant Category of Assessment

Technical assessment

Scope

The entire network

Data Collection Methods

Examination of the functional specifications of the different ATT-applications (see [14]) providing a priori analysis of the potential of integration at the data acquisition and storage level. A posteriori (examining which data are used to what extent in real-life operation, e.g. by studying the log-books).

6.5.1.4. Extent of Integration at the Central Control level (IntCC)

Definition

The extent of integration at the central control level as defined by the proportion of control settings generated which is issued for all relevant ATT-applications, and generated by the same control procedure, within a suitable collection of events.

The indicator aims to reflect the level of integration for centralised control strategies.

Concept of Calculation

Let $\text{App}_{ct}$ denote the set of controlled applications to which the control settings $c(t)$ are issued at time $t$. If $N_{\text{app}}$ denotes the number of applications which are in principal controlled integrally, then the extent of integration can be calculated by using the following equation:

$$\text{Int}_{CC} = \sum_{t=1}^{T} \frac{|\text{App}_{ct}|}{N_{\text{app}}}$$

where $T$ denotes the time horizon chosen (typically a day).
Relevant Category of Assessment
Technical assessment

Scope
The entire network

Data Collection Methods
Examination of the functional specifications of the different ATT-applications (see [14]) providing a priori analysis of the potential of integration at the data acquisition and storage level. A posteriori (examining which ATT-applications are controlled by the control settings issued in real-life operation, e.g. by studying the log-books).

6.5.1.5. Extent of Integration at Message Diffusion Level (IntMD)

Definition
The extent of integration at the message diffusion level is defined by the proportion of messages verified and finally issued on all relevant information providing ATT-applications (VMS-, or VDS-systems).

This indicator is used to assess the strength of integration at the final message distribution level.

Concept of Calculation
Let $App_{c(t)}$ denote the set of controlled applications to which the control settings $c(t)$ are issued at time $t$. If $N_app$ denotes the number of applications which are in principal controlled integrally, then the extent of integration can be calculated by using the following equation:

$$IntCC = \sum_{t=1}^{T} \frac{|App_{c(t)}|}{N_{app}}$$

where $T$ denotes the time horizon chosen (typically a day).

Relevant Category of Assessment
Technical assessment

Scope
The entire network

Data Collection Methods
Examination of the functional specifications of the different ATT-applications (see [14]) providing a priori analysis of the potential of integration at the data acquisition and storage level. A posteriori (examining which messages generated at central level are used by the different VMS-, and VDS-applications in real-life operation, e.g. by studying the log-books).
7. **EXPERIMENTAL SET-UP (1): TECHNICAL ASSESSMENT**

7.1. Introduction

At the most basic level of assessment, the *technical assessment*, the 'technical parameters' of system performance are determined:

> *Technical Assessment*

> "the process of determining the extent to which technical requirements are met."

Apart from the more obvious aspects of technical assessment, such as the determination of systems' accuracy, delays, and sensitivity, also the extent of integration at the divers levels is catalogued as a kind of technical assessment: the 'technical performance of integration'.

Summarising, for technical assessment in DACCORD, the following performance indicators have been proposed:

**Common Indicators:**

- Incident Detection Delay (*IDL*);
- Congestion Detection Delay (*CDL*);
- Information Displaying Delay (*InfoDL*);
- Modification and Cancellation of Information Delay (*ClinfoDL*);
- System's Processing Time (*SPT*);
- Average Application Failure Time (*AFT*);
- Accuracy of Output provided by Application (*AccO*);
- Sensitivity to Inaccurate Input (*SensI*).

**Indicators with respect to Integration:**

- integrated Information Communication Delay (*IntInfCL*);
- Cancellation of Information delay for integrated systems (*IntCInfoDL*);
- Extent of Integration of Data Sources (*IntDS*)
- Extent of Integration of Data Acquisition and Storage Facilities (*IntDB*);
- Extent of Integration at Data Processing Level (*IntDP*);
- Extent of Integration at Central Control Level (*IntCC*).

Using these indicators for all the DACCORD test-sites, enables technical assessment at two levels:
1. the assessment of the technical performance of the system, if compared to some technical generally accepted standard\(^{12}\);

2. the comparison between the different candidate systems. In this case, the purpose of a technical evaluation is to identify which solution can best achieve technical requirements and intended objectives.

The values of the indicators proposed can be determined, and compared to the accepted standards for the value of this indicator (e.g. admissible failure rate, or the admissible monitoring, estimation and prediction error), and between the different sites.

In case of evaluation the predictive quality of the different traffic forecasting models in DACCORD (e.g. STF, METACOR, BTM), comparison with historic and realised measurements are performed (note that this requires the storage of predictions for relevant control alternatives at key-moments, in order to be able to compare predictions concerning the state of the network with actual measurements). In this respect, the hierarchy monitoring-estimation-prediction should be taken into account carefully (sensitivity of the prediction-subsystems).

Results of laboratory or field trials or other experiments may be used as input for a technical evaluation. The results from a technical evaluation may affect decisions on whether the system under consideration justifies further assessment, that is user-acceptance, impact assessment, and socio-economical assessment.

### 7.2. Experimental Set-Up

#### 7.2.1. Introduction

In this section, the different aspects of technical assessment with respect to the different validation objectives are presented. Basically, two levels are distinguished:

1. generic validation objectives;

2. application specific validation objectives.

Additionally, the overall definition of success is indicated with respect to the different experimental technical assessment objectives. The data used are typically log-files and data for the entire study period, that is typically six to eight weeks.

**Verification and Demonstration**

The verification stage needs to show that the systems technically perform to such a high level of reliability and performance, that initiating a demonstration stage is justified.

Hence, technical assessment plays a decisive role in the verification stage of the systems. Furthermore, since initially the variability in operations of the different DACCORD applications is unknown, the verification stage can be beneficial to estimate the level of significance resulting from a six to eight week measurement

\(^{12}\) With technical assessment, the reference case is usually an accepted standard for the indicator associated with a particular validation objective. For example, evaluation of applications for the monitoring-, estimation- and prediction- quality of the traffic system can be established by means of comparison with actual measurements, and/or historic data.
period, and eventually provide statements with respect to the necessity of additional measurements in the demonstration stage.

7.2.2. Generic Validation objectives and Performance Indicators for Technical Assessment

<table>
<thead>
<tr>
<th>Validation objective to establish:</th>
<th>Performance Indicators</th>
<th>Overall Definition of Success/Comments</th>
</tr>
</thead>
</table>
| • whether the technical functioning and the reliability of the ATT-application complies to the accepted technical standard by studying systems' delay | IDL, CDL, InfoDL, CInfoDL, SPT, IntInfCL, IntInfoDL | IDL < 2 min.  
CDL < 2 min.  
InfoDL < 30 sec.  
CInfoDL < 20 sec.  
SPT < xx sec.  
IntInfCL < 10 sec.  
IntInfoDL < 10 sec. |
| • whether the technical functioning and the reliability of the ATT-application complies to the accepted technical standard by studying systems' failure rate | AFT | AFT < 10% |

Table 35: Generic Validation plan for Technical Assessment
7.2.3. Disclaimer with Respect to Overall Definition of Success

According to the CONVERGE guidelines, providing the European Commission with the specifications of 'the overall definition of success' with respect to the performance indicators for all validation objectives is mandatory.

However, since the DACCORD tools and applications are state-of-the-art and not yet implemented and functioning, knowledge concerning the performance of these tools and applications is not known precisely. Therefore, specifying a threshold value for the 'overall definition of success' for all validation objectives was considered to be a near impossible task.

Therefore, the evaluation manager would like to stress that the values determining whether or not the ATT-tool or application has been a success, might need additional modification when experimental results become available.
8. EXPERIMENTAL SET-UP (2):
USER ACCEPTANCE ANALYSIS

8.1. Introduction

For user-acceptance analysis, the following definition is adhered:

User Acceptance Analysis “the process of estimating users' attitudes to and perception of the separate ATT-applications.”

User acceptance assessment can be based on questionnaire surveys, interviews, etc. However, user-acceptance analysis can also be estimated using indirect methods.

For road-users, the user acceptance is estimated in terms of improvements in safety, reduction of vehicle operating costs, saving in travel time, improvement in driving comfort. Hence, the determined system performance influences the driver acceptance. Therefore, user-acceptance analysis with respect to the road-user is addressed using the results of both the technical, impact- and socio-economical assessments.

Regarding acceptance by system operators, the results of dedicated technical evaluation, impact assessment and cost-benefit analysis for the respective system are usually decisive. User-friendliness of the human-machine interface may be an additional factor influencing the system operator's acceptance.

8.1.1. Performance Indicators for User-Acceptance Analysis

Common Indicators:

- Information Coverage Ratio (InfoCR);
- Operators' Credibility Factor (OCrF);
- Operators' Comprehensibility (OComp);
- Operators' Comfort & Stress-level (OCSL);
- Operator's Utility Rate (OUR);
- Compliance Rate (CR).

As mentioned, user-acceptance is (indirectly) determined by the results of technical-, impact-, and socio-economic assessment. The performance indicators with respect these categories of assessment are not recalled in this section; we refer to the sections for the respective category of assessment in these sections.

8.2. Data Requirements

The data requirements for user-acceptance analysis can be summarised by the following points:

- Description of the VMS- or VDS-dissemination services (static data, and log-files):
- location of VMS- and VDS-signs;
- description of the system-operator information strategies;
- recordings of VMS- or VDS-operating times;
- log-files of events (location and time of occurrence), and situations;
- traffic flows, speeds, and possibly OD-relations.

- Interviews with system operators, concerning the
  - credibility of provided information: assistance (e.g. provided options control settings), estimations, and predictions;
  - comprehensibility of provided information;
  - comfort or stress experienced by the operators;
  - overall perceived utility of the application.

### 8.3. Experimental Set-Up

#### 8.3.1. Introduction

In the experimental set-up for user-acceptance analysis, the proposed validation objectives are connected to the different performance indicators presented for conducting user-acceptance analysis.

In principle, the different validation objectives are application-dependent. However, for reasons of clarity, in the tables presented, common validation objectives and common performance indicators are given for different ATT-applications.

In principle, the level of significance of accepting or rejecting the hypotheses settled by the overall definition of success, depends on the number of sample (interviews, or measured impacts, e.g. splitting rates) taken. However, due to the fact that the number of people working in the TCC’s is bounded, the level of significance of the test based on the interviews does not only depend on the sample size, and inter-operator variability of the answers, but also on the population size.

Clearly, for the level of significance of changes in e.g. splitting proportions, indirectly reflecting drivers acceptance of the information provided, depends primarily on the sample-size, and the variability, and is addressed in the chapter on impact assessment.

#### 8.3.2. Verification and Demonstration

For assessment of the technical performance of the tools and applications being assessed, no distinction is made between the verification and demonstration stage.

#### 8.3.3. Validation Plan

The following tables depict the relation between the different DACCORD ATT-tools and applications, the validation objectives, the relevant performance indicators, and overall definition of success for user-acceptance analysis in DACCORD.
### DACCORD Application

**Data Cleaning Systems**
- Level of confidence in acceptance of information provided by the ATT-application
- Level of quality/ergonomics of the information provision system about the state of the transportation network
- Whether the ergonomics/ flexibility for operator intervention are off acceptable standard

**Validation objective to establish:**

<table>
<thead>
<tr>
<th>Validation objective</th>
<th>Perf. Ind.</th>
<th>Overall Definition of Success/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OCRf</td>
<td>OCRF &gt; 80%</td>
</tr>
<tr>
<td></td>
<td>OComp</td>
<td>OComp &gt; 95%</td>
</tr>
<tr>
<td></td>
<td>OCSL</td>
<td>OCSL &gt; 8</td>
</tr>
<tr>
<td></td>
<td>OUR</td>
<td>OUR &gt; 8</td>
</tr>
</tbody>
</table>

**Section-, or Network Level Estimation and Prediction**
- Level of confidence in acceptance of information provided by the ATT-application
- Level of quality/ergonomics of the information provision system about the state of the transportation network
- Whether the ergonomics/ flexibility for intervention by the operator are of an acceptable standard

<table>
<thead>
<tr>
<th>Validation objective</th>
<th>Perf. Ind.</th>
<th>Overall Definition of Success/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OCRF</td>
<td>OCRF &gt; 80%</td>
</tr>
<tr>
<td></td>
<td>OComp</td>
<td>OComp &gt; 95%</td>
</tr>
<tr>
<td></td>
<td>OCSL</td>
<td>OCSL &gt; 8</td>
</tr>
<tr>
<td></td>
<td>OUR</td>
<td>OUR &gt; 8</td>
</tr>
</tbody>
</table>

**Point-, Section, and Network level Control**
- Improvement in the information coverage ratio (penetration) due to implementation of the ATT-application
- Improvement in the information coverage ratio (penetration) due to implementation of the ATT-application
- Level of quality/ergonomics of the information provision system about the state of the transportation network
- Whether the ergonomics/ flexibility for intervention by the operator are of an acceptable standard
- Compliance rate of road-user to road-guidance/ ramp- or mainline metering
- Road-users response to information on travel times/queue lengths provided by the VMS

<table>
<thead>
<tr>
<th>Validation objective</th>
<th>Perf. Ind.</th>
<th>Overall Definition of Success/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ICR</td>
<td>ICR &gt; 80%</td>
</tr>
<tr>
<td></td>
<td>CR</td>
<td>CR &gt; 90%</td>
</tr>
<tr>
<td></td>
<td>Sp</td>
<td>Changes in Sp &gt; 2%</td>
</tr>
</tbody>
</table>

**Integration of Control Measures, and Estimation and Prediction Tools (OSS- and CTMS-systems)**
- Level of confidence in acceptance of information provided by the ATT-application (e.g., regarding the predicted impacts of control measures and settings proposed by the system operators)
- Level of quality/ergonomics of the information provision system about state
- Whether the ergonomics/ flexibility for intervention by the operator are of an acceptable standard
- Improved compliance rate of road-user to road-guidance due to improvements in reliability of the information provided
- Road-users response to information on travel times/queue lengths provided by the VMS due to improvements in reliability of the information provided
- Improvement in the information coverage ratio (penetration) due to implementation of the ATT-application

<table>
<thead>
<tr>
<th>Validation objective</th>
<th>Perf. Ind.</th>
<th>Overall Definition of Success/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OCRF</td>
<td>OCRF &gt; 90%</td>
</tr>
<tr>
<td></td>
<td>OComp</td>
<td>OComp &gt; 95%</td>
</tr>
<tr>
<td></td>
<td>OCSL</td>
<td>OCSL &gt; 8</td>
</tr>
<tr>
<td></td>
<td>OUR</td>
<td>OUR &gt; 8</td>
</tr>
<tr>
<td></td>
<td>CR</td>
<td>OCRF &gt; 80%</td>
</tr>
<tr>
<td></td>
<td>intICR</td>
<td>intICR &gt; 80%</td>
</tr>
</tbody>
</table>

**Connection with remote TCC**
- Level of confidence in acceptance of information provided by the ATT-application
- Improving the level of knowledge of the system-operator on external traffic conditions
- Level of quality/ergonomics of the information provision system about the state of the transportation network, and the remote transportation network

<table>
<thead>
<tr>
<th>Validation objective</th>
<th>Perf. Ind.</th>
<th>Overall Definition of Success/Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CrF</td>
<td>OComp &gt; 95%</td>
</tr>
<tr>
<td></td>
<td>OUR</td>
<td>OUR &gt; 8</td>
</tr>
<tr>
<td></td>
<td>OComp</td>
<td>OComp &gt; 95%</td>
</tr>
<tr>
<td></td>
<td>OCSL</td>
<td>OCSL &gt; 8</td>
</tr>
<tr>
<td></td>
<td>OUR</td>
<td>OUR &gt; 8</td>
</tr>
</tbody>
</table>

### Table 37: Experimental Set-Up for User-Acceptance Analysis
9. EXPERIMENTAL SET-UP (3): IMPACT ASSESSMENT

9.1. Introduction

Impact assessment is defined by:

"the measurement or estimation of the effects of a candidate ATT-tool, for example the impacts on safety, environmental conditions, or efficiency of the transportation system, with respect to the target user-groups likely to be affected."

Since this means determining how the indicators of assessment may have changed, a comparison is implied: either a "before-and-after" measurement, or comparison with other candidate ATT-applications.

In DACCORD, impact assessment is based on the results of field trials, of other experiments or calculations, e.g. modelling or simulation. Impact assessment provides input for socio-economic evaluation, and supports the decision process directly.

This chapter describes a number of tools and methodologies for the assessment of the impacts of ATT-applications of the transportation systems in DACCORD.

The chapter can roughly be divided into three parts:
1. basic considerations with respect to DACCORD impact assessment;
2. general tools for the assessment of (isolated or integrated) ATT-applications;
3. tools and methodologies for the assessment of the additional gains or losses due to integration of DACCORD ATT-applications at distinct levels;
4. tools and methodologies for the assessment of the impact of individual ATT-applications from measurements of the integrated ATT-systems.

This introduction section finishes with some basic considerations with respect to problems regarding the assessment of the integrated DACCORD applications.

9.1.1. Performance Indicators for Impact Assessment

Indicators according to Functions:

- Instantaneous Travel Time (iTT);
- Actual Travel Time (aTT);
- Travel Time Loss (W);
- Cumulative Travel Time Losses (cumW);
- Mean Speed (V);
- Performance (P);
- Traffic Flow Rate (q);
- Speed Variance (sV);
9.1.2. Basic Considerations regarding Assessment of Integrated DACCORD ATT-Applications: Reference Cases

For impact assessment, the following remarks concerning problems possibly encountered can be made:

Absence of a true ‘ZERO’ situation

Since currently, a system of individual applications (e.g. stand alone ramp-metering, dynamic route information provision) is already present, a true ‘ZERO’ situation does not exist: traffic operations have already been changed in the current situation (e.g. congestion has already been re-distributed to some extent).

Ideally, the reference case would be a traffic system without dynamic traffic management measures present. However, this situation is not practically feasible. On the one hand, it is inconceivable that the entire traffic management system is shut down temporarily for evaluation purposes due to opposition of both network managers and system operators.

In this respect, it should be mentioned that, on the one hand, some of the site-managers have not ruled out the possibility of temporarily shutting down distinct ATT-applications for assessment purposes. By doing so, the direct effects of the ATT-application can be assessed.

On the other hand, even if the system could be turned on and off temporarily, the behaviour of road-users displayed cannot be regarded to be representative: generally, the equilibrium effects of an application can only be assessed if the application is running for a certain period of time (e.g. road-users need to familiarise themselves with route-information; only after some time, road-users choice behaviour stabilises with road-users considering both historic information (memory), confidence in the information or directives, habit forming, and the actual information provided by the ATT-applications.
Exogenous Disturbances

Due to the length of the DACCORD project, it is conceivable that the autonomous growth of the freeway traffic results in additional load of the network. Traffic demand on alternative routes will grow due to this exogenous disturbance. Traffic flows from distinct Origin Destination relations may display different growth-rates, complicating evaluation of impacts from a.o. VMS-systems. Other disturbances are e.g. traffic composition, emerging technologies, and changing driver-behaviour.

Synergetic Effects

With the introduction of each new (isolated) application developed for control of traffic operations (for example, a new ramp-metering system, a dynamic route information panel, or a software module for the assistance of rerouting advice to traffic operators in case of incidents) the characteristics of the total traffic system change.

Therefore, cross-comparison between the recently implemented application and previously installed applications cannot be obtained from the evaluation results of the individually implemented ATT-tools and applications, since these results in effect address the additional value (either positive or negative) of the application, i.e. the performance of the system compared against the performance of the system without the application (the reference case). Recall the definition of ‘synergy’:

“the way the effects of the simultaneous utilisation of the ATT-tools and applications compare to the sum of separate effects”

Evaluation programmes should take great care in the interpretation of the impacts and additional effects of introducing an tools or application, due to either negative or positive synergetic effects. Moreover, assessment of the effects and impacts of an individual applications is complicated.

Independently of the evaluation within the DACCORD programme, the site managers will perform their own evaluation studies of the different ATT-applications implemented at their sites. The evaluation reports resulting from these studies can be used in the evaluation of synergetic effects caused by the different isolated, by mutually influencing, ATT-applications (by means of meta-analysis).

9.1.3. Expected Effects of Tools and ATT-Applications

When assessing the impacts of ATT-applications and tools, it is very important to distinguish three different levels of effects:

- the direct effects resulting for the introduction of the different DACCORD tools and applications;
- the indirect effects of the applications;
- the new equilibrium state of the transportation system.

Direct Effects

When different ATT-applications are installed, their primary aim is to influence the behaviour of the road-users by actuation, either using soft control measures, such as the provision of information (prescriptive, or descriptive), and speed recommendations, or hard control measures, such as ramp-, and mainline metering, and lane usage control. Clearly, if the behaviour of the road-users is not affected by the ATT-application, implementation of the application cannot be beneficial to the
efficiency of the transportation system, the safety of the road-users, the impacts on the environment, etc.

Basically, the direct effects of implementation of the different ATT-applications are the direct changes in route-choice, driving speeds, lane choice, and merging behaviour (see Figure 19).

In addition to the direct effects of the applications, indirect effects will be experienced. Since a number of road-users change their route-choice, speed- and lane-choice, and merging behaviour, the situation on the transportation system changes. Consequently, the control settings of the distinct ATT-applications will change (changes in the displayed travel time, or queue lengths, different cycle time for ramp-metering installation, different recommended speed).
Finally, when the different ATT-applications and tools have been in operation for some time, a new equilibrium state may have evolved. In this new equilibrium state, behavioural characteristics of the drivers, other than the ones exhibited by the direct, or indirect effects of the ATT-applications, may have changed, due to implementation of the ATT-applications. For example, road-users may have changed their departure times, or their modal choice.

Figure 20: the Indirect Effects of ATT-Applications and Tools

Figure 21: Equilibrium Effects of the ATT-Applications
It is unsure whether an equilibrium state will be reached, depending on the stability of the transportation system, and the period between implementation and evaluation. However, if the system has reached its new equilibrium-state, the indirect effects are difficult to assess, since the systems state is equals the effects caused by the ATT-applications. Consequently, depending on the time-span between implementation and evaluation, a mixture of indirect and equilibrium effects are measured. The extent of the systems advancement to the equilibrium state (tendency to equilibrium) can be assessed by analysing the day-to-day variability of relevant indicators of performance (e.g. travel times, performance, weight of congestion).

![Figure 22: Basics for before- and after-Study Approach](image)

Hence, the before- and after-study primarily captures the indirect and equilibrium-effects of the ATT-applications.

### 9.2. Tools for Data Analysis: Direct Effects

#### 9.2.1. Introduction

The direct effects resulting from implementation of ATT-applications can be measured by using 'direct' approaches. For DACCORD, *stimuli-response* techniques...
have been chosen, in order to measure these direct effects. For this technique, no before-study is necessary. In the sequel of this section, the technique is briefly outlined.

9.2.2. The Basics of the Stimuli-Response Technique

The key to the stimuli-response technique is the definition of both relevant stimuli and responses exhibited by the transportation system, or the road-users. Using these stimuli, we aim to contemplate to which extent the road-users change for example their cruising speeds or their route choices. The stimuli-response technique is important when assessing the direct effects of soft control measures, such as speed recommendation, and the provision of either descriptive or prescriptive information. However, specific aspects of hard control measures, such as compliance to ramp- or mainline-metering control, or lane usage, can also be assessed using stimuli-response techniques.

The main benefit of the stimuli-response technique is its ability to measure the effect of an ATT-application on different performance indicators, irrespective of an inevitable amount of noise inherent to the traffic process. These effects which we want to measure may be too small to be distinguished from noise. However, using correlation-analysis, these effects can be measured, by assessing if changes in the 'stimuli-signal' are correlated to changes in the 'response-signal', by observation of changes in both stimuli and response signals, during a certain time-period. Since the measurements will be 'blocked', the disturbances caused by changes in traffic-conditions, such as weather-, modal-, and departure time-changes are limited.

It is beyond the scope of the evaluation plan to describe to which aspects of the transportation process stimuli-response techniques are applied. However, at least the impact of VMS-, and VDS-systems on route choice (split proportions at a diverge), and the impact of speed recommendations on the cruising speed of the drivers are proposed. In the sequel of this section, an example of the application of the stimuli-response technique is discussed.

9.2.3. Example: Stimuli-Response Technique applied to compare Provision of Queue-length Strategy and Travel-Time Strategy on Route-Choice

Suppose we aim to compare strategies with respect to the provision of information regarding the direct effects on route-choice. We wish to compare two strategies:

1. provision of queue-length information of two different route-alternatives;
2. provision of (instantaneous) travel-time information of two different route-alternatives.

To this end, we defined the following stimuli:

\[ S = \text{unexpected difference}^{13} \text{ in queue-lengths between routes} \]
\[ S' = \text{unexpected difference in travel-times between routes} \]

By using the difference between the current queue-length or travel-time, i.e. by analysing the effect of unexpected queue-lengths and travel-times, the effect of

---

13 The unexpected difference is defined by the current differences between queue-lengths or travel-times between alternative routes, compared to the period-averages of these differences.
information provision is expected to be larger in comparison to provision of information which road-users expect (although the latter can also influence route-choice, due to improved reliability of the route travel time).

The expected impact of the provision of information is that drivers change their routes. Hence, some drivers are bound to use an alternative section at the bifurcation point. Consequently, the following response is defined:

$$R = \frac{SP(t) - SP}{SP}$$

Figure 23: Dynamic Route Information and Splitting Proportions

For both cases, both stimuli ($S$, and $S'$) are determined, and the respective response $R$ is calculated. Subsequently, regression analysis (see section 9.3.2) is applied, and a relation between both stimuli and the response is resolved.

Figure 24: Differences in Regression between Stimuli and Response

Although the outlined method will not exemplify which of the two methods results in the most beneficial efficiency, e.g. smallest travel time for road-users, best throughput of the transportation network, it will enable determination of the
effectiveness of either strategies with respect to influence the route-choice behaviour of road-users.

9.3. Tools for Data Analysis: Indirect, and Equilibrium Effects

In general, the assessment of ATT-applications should not be restricted to the calculation of performance indicators. It is argued that dedicated statistical analysis is needed to provide insight in the increase or decrease of the level of performance of the DACCORD ATT-systems.

In this section, a number of tools for assessment of the DACCORD ATT-applications are presented.

9.3.1. Period Averages, Variances, and Medians of Performance Indicators

The most basic assessment tool is the comparison between the average values of the different indicators identified. In this approach, the traffic counts and speed measurements collected for the time period $t$ are averaged over days $d$. Non-working days (Saturday, Sunday, and holidays) are omitted in the averaging process. Additional stratification may be necessary, e.g. days where incidents have taken place, day with very bad weather conditions, etc.

If possible, the average values found for the different performance indicators for the different measurement periods, i.e. the before and after-case, or the different candidate systems in DACCORD, are then compared, and conclusions can be drawn.

Additionally, the sample variances accompanying these averages are computed from the traffic counts and speed measurements. These variances serve two purposes. First, the variance of the sample can be used to estimate the significance of the sample taken. Secondly, for specific indicators, the variance indicates the level of variability, and consequently the reliability of the transportation system. Both are discussed briefly in the following subsections.

9.3.1.1. Determining Sample Size

The determination of the sample size presents a trade-off between expenses, either due to data collection or due to the processing of the collected data on the one hand, and reliability and variance on the other hand. Basically, the sample size should ensure a representative sample, from which valid conclusions can be drawn.

For a single measurement point (understation), sample error is introduced when the number of samples in the measurement-periods is too small. To illustrate this, first consider a one-day one-period sample, based on inductive loop measurements. Suppose that the inductive loop station $i$ measures passage times of vehicles passing the loops. The flow-rate $q_i(t;d)$ is calculated from the number of vehicles $n_i(t;d)$ which passed the measuring point during the interval $t$ at day $d$. This number $n_i(t;d)$ can be seen as a sample from a random variable $N(t)$, which is assumed to be independent on the day of measurement $d$. Let:

$$\bar{n}(t) = \frac{1}{m} \sum_{d=1}^{m} n_i(t;d)$$
then, for large populations and small sample sizes (see [18]), we have:

\[
se(\overline{t}(t)) = \frac{S}{\sqrt{m}}
\]

where \(m\) denotes the sample-size, \(S\) denotes the sample-variance, and \(se(n)\) denotes the required standard-error of the mean. Clearly, the required sample size would be:

\[
m = \frac{S^2}{se(\overline{t}(t))^2}
\]

When using this formula for the determination of the required sample size, the following problems are encountered:

1. the sample variance \(S\) can only be calculated when the sampling already has been carried out;

2. choosing an acceptable standard for the standard error for the mean.

An approach taken is to first take a pilot sample, thereby obtaining a first impression of the variability of the process: from this pilot sample, the sample variance is calculated. Using this sample variance, an 'acceptable' standard error for the mean can be obtained by specifying a confidence level for the interval around the mean (how frequently are we prepared to make a mistake). After this, the limits of the confidence interval around the mean (expressing sample size as a function of the expected coefficient of variation) can be specified, and the necessary number of samples can be determined.

Another approach would be an iterative one: after obtaining a sample, the error around the mean is calculated. If this error does not live up to an accepted standard, additional sampling is necessary, and performed.

9.3.1.2. Hypotheses

After determination of the value of the performance indicator at time \(t\) of the different days \(d\) of interest, analysis of the distribution of this performance indicator is applied, using either the empirical distribution, or Kernel estimation techniques (see [17]). Using these techniques, indications are given on the form of the distribution of the performance indicator being assessed in different periods.

We assume that the performance indicator has a Normal distribution. If not, it is assumed that the distribution can be transformed into a Normal distribution.

Traffic measurements are available either for both the 'before case', and the 'after case', or for two candidate systems implemented in the same or common transportation system.

The question to be answered is the following 'Is there a significant shift in the mean value of the performance indicator?'. Hence, the null-hypothesis is:

\[H_0: \text{no difference in the mean value of the performance indicator}\]

\[H_1: \text{there is a significant shift in the mean value of the performance indicator}\]

\[14\] In this case, the population size, that is the total number of available days, is assumed to be relatively large, in comparison to the sample size. Hence, the dependence on the population size, present in the Central Limit Theorem is dropped.
We are prepared to accept a Type I error (reject a true null-hypothesis) of $p\%$. Clearly, a two-sided test is performed, since it is uncertain if the value of the indicator will increase or decrease.

In the following sections, the 't'-test, and variance analysis methods, which can be used to test hypotheses comparing mean values, are described and applied for evaluation in DACCORD.

9.3.1.3. 't'-tests

The 't' test is appropriate for comparing the mean values from two samples. Different formulae for computing the 't' value are appropriate where the standard deviations from the two samples are assumed the same or are different.

The calculated 't' statistic must be checked in order to see whether it exceeds the critical value. This depends upon the Type I error — probably 5% — and the number of degrees of freedom (the sample size). The software package MATLAB™ used, has standard procedures to perform one- or two-sided 't'-tests.

9.3.1.4. Analysis of variance - 'one-way'

Analysis of variance assumes that variation in the data can be partitioned into:

1. systematic variances, which can be attributed to among others candidate application, weather conditions, time of day, etc.;
2. residual (within-group) variances.

In 'one-way' analysis of variance only one factor (which may define many groups) is considered. For performance indicators in DACCORD, the sample variation can be split into:

1. the variation caused by implementation of the different transport telematics applications in DACCORD;
2. the residual variation of the performance indicator due to the variability of the traffic process.

Since only one factor is analysed, measurements are stratified in blocks with common characteristics (e.g. comparable weather conditions, comparable periods of day, that is morning- or evening rush-hour, off-peak period, etc.). This process is called 'blocking'.

Measurement Block

"a measurement block is a defined environment for a measurement, in which conditions which could influence the indicators investigated should be kept as constant as possible."

The variance between the telematics applications divided by this residual (within-group) variance gives the 'F'-value, whose probability of occurrence can be found either from published tables or computed by a computer package (MATLAB). If the 'F'-value is sufficiently large such that one can be $(100-p)\%$ certain that it was not by chance, then the null hypothesis that there are no differences between the transport telematics applications can be rejected.

Example: Isolated Applications vs. Integration of Application

Consider two cases: first, consider the case where no integration of various ATT-applications installed and operating is present. This will be the reference case 0. Subsequently, integration at various levels is introduced to the transportation system (integration at the central control level, or message dissemination level). Let
m denote the level of integration (see section 9.5.2). In both cases, speed and traffic count-samples are obtained.

Next, we want to test whether the total queue weight (tQW) in the morning peak-hour has changed from the reference period. To this end, let tQW_m(d) contain samples of the total queue weight of day d for case m=0,...,M (M denoting the number of cases). The following is hypothesised:

H_0: the mean total queue weight has remained unchanged due to integration

In the following table, example samples are given (in this case for cases where equally large samples have been obtained).

<table>
<thead>
<tr>
<th>Case m</th>
<th>Samples obtained for m</th>
<th>Case mean = tQW_m</th>
</tr>
</thead>
<tbody>
<tr>
<td>0: no integration</td>
<td>56.7 45.7 48.3 54.6 37.7</td>
<td>48.6</td>
</tr>
<tr>
<td>1: data coll. integration</td>
<td>64.5 53.4 54.3 57.5 52.3</td>
<td>56.4</td>
</tr>
<tr>
<td>2: contr. integration</td>
<td>56.7 50.6 49.5 56.5 44.7</td>
<td>51.6</td>
</tr>
<tr>
<td>Day mean = \bar{tQW}(d)</td>
<td>59.3 49.9 50.7 56.2 44.9</td>
<td>tQW = 52.2</td>
</tr>
</tbody>
</table>

Table 38: Example of total Queue Weight Samples (morning peak-hour)

The remaining question is: are the sample for the separate cases statistically different? By using the one-way variance analysis discussed, an answer can be found using the following statistic (the 'F'-statistic):

\[ F = \frac{D \cdot s^2_{tQW}}{s^2_m} \]

where D=5 denotes the number of days, m the reference number, s_m the sample-deviation within the samples of case j, and s_{tQW} the sample variance of the case-averages with respect to the total average queue length, i.e.:

\[ s^2 = \frac{1}{(D-1)} \sum_{d=1}^{D} \left( tQW_m(d) - \bar{tQW}_m \right)^2 \]

\[ s^2_{tQW} = \frac{1}{M} \sum_{m=0}^{M} \left( tQW_m - \bar{tQW}_m \right)^2 \]

Clearly, on the one hand F is an monotone increasing function of both D (the number of samples for each case j), and the total sample variance. On the other hand, F is a monotone decreasing function in the within case sample deviation. Hence, if large fluctuation of within case observations are apparent, F decreases. As F decreases, the p-value accompanying the value of F increases. Consequently, the hypotheses H_0 can only be rejected at a decreasing level of significance (1-p)100%. Similarly, enlarging the number of samples decreases the level of significance. Note that F is F-distributed with (D-1,(j+1)\cdot(D-1)) degrees of freedom.

From Table 38 we find:

\[ F = \frac{77.4}{35.7} = 2.17 \]
At this value, we have $P_F(2.17) = 0.8425$, where $P_F$ is the probability-function of the $F$-distribution. Consequently, for tests with level of significance less than 15.75%, $H_0$ is accepted. At test of higher significance value, the hypotheses needs to be rejected. For a more elaborate discussion on one-way variance analysis, for example when sample sizes are unequal, the determination of confidence intervals, etc., see [19].

9.3.1.5. Analysis of variance - 'many-way'

This technique is appropriate if there are several factors of interest, e.g. alternative transport telematics applications, different periods of day, different weather conditions, etc.

The strength of many-way analysis of variance is the fact that it provides the possibility to strengthen differences between the different cases, due to explanation of unexplained variance between the different samples. When the unexplained variance $s_n^2$ in the previous example could be reduced, the $F$ value would increase. With the increase of $F$, differences between the cases are detected earlier, since $H_0$ is rejected at a lower value for the significance level.

Example Continued: two way analysis of variance

Suppose that the day of the week, that is Monday, Tuesday, Wednesday, Thursday, and Friday, is considered to be an important co-variable, explaining at least some of the unexplained variance. Some of the days are assumed to structurally exhibit a more congested pattern than other days: the 'within case'-variance is not so big at all, there is just a wide difference between the congestion-patters of the individual days of the week. Removal of this 'noise' will provide for a much more powerful test of differences due to integration.

For two-way variance analysis, we define the day mean, the case mean, and the overall mean, by respectively:

$$
\bar{t}QW_m = \frac{1}{D} \sum_{d=1}^{D} tQW_j(d')
$$

$$
\bar{t}QD(d) = \frac{1}{M+1} \sum_{m=0}^{J} tQW_m(d)
$$

$$
\overline{tQD} = \frac{1}{D} \sum_{d=1}^{D} tQW(d') = \frac{1}{M+1} \sum_{m=0}^{J} \overline{tQW_m}
$$

The sample-variances are derived accordingly. It is observed that the following holds:

$$
\text{total variance} = \text{day variance} + \text{case variance} + \text{random variance}
$$

where:

$$
\text{random variance} = \frac{1}{D \cdot (J+1)} \sum_{d=1}^{D} \sum_{m=0}^{J} (tQW_m(d) - \overline{tQW_m})^2
$$

Since the difference between the different cases is relevant, the following $F$-statistic is defined:

$$
F = \frac{\text{variance explained by cases}}{\text{random variance}}
$$

Since $\text{variance explained by cases} = 77.4$, and the $\text{random variance} = 5.9$, we find $F = 13.1$. The $p$-value equals 0.003, implying that $H_0$ can be rejected for test with significance.
value smaller that 0.3% (i.e. a 5% significance level-test will be rejected). Clearly, this two-way variance analysis is more powerful than the one-way version.

9.3.1.6. Time Series of Sample-Median

As an alternative to the sample average, the sample median can be used. It is well known that, whenever the sample exhibits large fluctuations, for example extraordinary travel times caused by an accident experienced at one specific day of the sample, the sample mean may be significantly affected.

The sample median is more robust with respect to these fluctuations. Furthermore, in some cases, the median of the sample exhibits a higher level of sample efficiency than the sample mean, depending on the underlying distribution of the sample taken (see [19]).

9.3.2. Regression Analysis using distinct Co-Variables

In the methods outlined in Section 9.3.1, methods for the analysis of the changes in the means and variances of several (cumulated or averaged over distinct periods of interest) performance indicators, have been discussed. Using these methods, it is possible to judge the improvements of degradation of (parts of) the transportation systems in a statistically significant manner.

However, the cause for performance improvement or degradation is not addressed explicitly: as has been mentioned in the introductory section of this chapter, various exogenous effects (for example autonomous increase in traffic demand, or emerging vehicle-technologies, and changing driver-behaviour) can directly affect the performance of the DACCORD transportation systems. Hence, it is invaluable to estimate these effects quantitatively.

One approach is to use an explanatory co-variable — different from the most trivial ones, i.e. time, day of week — which to a large extent determines the overall performance of the system, or better, describes the current state of the transportation network more effectively than time of day, or day of the week. Examples of such co-variables are performance $P$, number of cars on the network $n$, and (total-) intensity $Q$ at specific points of interest (e.g. traffic demand at nodes).

Let $X(t;d)$ denote the co-variable, and let $Y(t;d)$ denote the studied performance indicator (e.g. $tQW(t;d)$).

At this point of the procedure, it is beneficial to produce a scatter-plot of points $(X(t;d), Y(t;d))$, in order to check visually whether any regression is perceptible, and what form of relation can be used to describe the regression between variable and co-variable, e.g. linear, or logarithmic.

In the ensuing of this section, linear regression is performed. If linear regression can not be identified, transformation of either the co-variable $X(t;d)$, or the performance indicator $Y(t;d)$ may result in a linear relation.

Standard linear regression analysis would involve the following linear relation:

$$ Y(t;d) = \alpha + \beta \cdot X(t;d) + \varepsilon(t,d) $$

where $\varepsilon(t,d)$ are equally and independently distributed random variables. Using the least-square technique, the following results are obtained ([19]):
9.3.3. Model-based Assessment Approaches — Derived Indicators

The model-based approach (derived indicators) to assessment is described in the section on assessment of isolated ATT-applications and tools in a integrated environment.

9.4. Application of Methods in DACCORD

In this section, the experimental design with respect to the statistical analysis using the methods described in section 9.3 above are outlined.

It is assumed that data consisting at least of traffic counts, and possible of speeds, are available, for the different periods of interest. These periods typically comprise traffic measurements of two- to three-month periods (at least the 'before', and — possibly several — 'after' periods). Furthermore, this data has been processed, resulting in time-series of the different performance indicators according to functions \( I_j(t;d) \), described in the previous chapter, per day \( d \), per time period \( t \).

Blocking is performed by stratifying the acquired data into block with comparable weather-, and incident/accident conditions. If specific conditions are infrequently encountered, these data are omitted from analysis.

Time Series Analysis

The different time-series are plotted against one-another, enabling inspection of collected measurements. By doing so, a first comparison of the different performance indicators, between the different reference periods can be made. The following indicators are analysed:

- for all links/routes of interest, the time-series of:
  - instantaneous travel time (\( \text{iTT} \)) and actual travel time (\( \text{aTT} \));
  - travel time losses (\( W \));
  - speed variance (\( \text{sV} \)) and hindering factors (\( \text{If} \));
- for the entire network, and all routes/links of interest, time series of:
  - cumulative travel time losses (\( \text{cumW} \));
  - performance (\( P \)), and maximum performance (\( \text{MP} \));
  - total queue length (\( tQL \)), and total queue weight (\( tQW \));
  - fuel consumption (\( FC \)), and exhaust gas emissions (\( EGE \)).
• for all links/routes of interest, and the entire network, the sample-'time'-variances\(^{15}\) of:
  ▪ instantaneous travel time \((iTT)\) and actual travel time \((aTT)\);
  ▪ travel time losses \((W)\);

**Statistical Testing of Differences**

Additional blocking is performed by stratifying the data into three day-periods: the morning rush-hour (6:30-10:30), the evening rush-hour (15:30-19:30), and the remaining off-peak period.

For each measurement period \(m\) (i.e. the ‘before’-period and the ‘after’-periods), period of day \(w\), the following values \(I_{jw}^{m}(d)\) are calculated for each day \(d\):

• for all links/routes of interest, the time-averages of:
  ▪ instantaneous travel time \((iTT)\) and actual travel time \((aTT)\);
  ▪ travel time losses \((W)\);
  ▪ speed variance \((sV)\) and hindering factors \((lf)\);

• for the entire network, and all links of interest, the sums of:
  ▪ cumulative travel time losses \((cumW)\);
  ▪ performance \((P)\), and maximum performance \((MP)\);
  ▪ total queue length \((tQL)\), and total queue weight \((tQW)\);
  ▪ fuel consumption \((FC)\), and exhaust gas emissions \((EGE)\);

• for all links/routes of interest, and the entire network, the sample-'time'-variances of:
  ▪ instantaneous travel time \((iTT)\) and actual travel time \((aTT)\);
  ▪ travel time losses \((W)\);

These values are determined for each day \(d\). Using two-way variance analysis, samples for each day \(d\) of these indicators, stratified by period of day \(w\), for period \(m\) result can be processed. This analysis allows resolving the following questions:

• has the mean value of the (time accumulated/averaged) indicator \(I_{jw}^{m}(d)\) changed due to implementation of the ATT-application(s) for the different periods of the day \(w\)?

• at what level of significance can the hypotheses that the mean value has not changed be rejected?

Alternatively, the time series remaining after averaging the performance indicator values at period \(t\) over the different days \(d\) can themselves be used as an input for the two-way analysis of variance. This will be especially beneficial if the time of day is a better factor for the explanation of variance.

\(^{15}\) As mentioned, the variance of the travel times reflect the reliability of the system.
9.5. Impact Assessment of Integration

9.5.1. Introduction and Preliminary Considerations

In the following sections, methodologies for the assessment of control systems, exhibiting various levels of integration of the distinct ATT-applications, are presented. The main focus in these chapters will be on the assessment of the added technical efficiency, the operational effectiveness, and the socio-economical impact of the integrated ATT-application.

A number of basic features of an integrated traffic control system environment, distinguishing it from isolated ATT-applications can be made:

9.5.1.1. Synergy

For the purpose of DACCORD evaluation we have defined synergy by:

"the way the effects of the simultaneous utilisation of the ATT-tools and applications compare to the sum of separate effects"

In this respect, the overall performance of an integrated system is a result of the:

1. individual performance (effectiveness) of the isolated ATT-applications;
2. level of integration, and techniques used for integration of the distinct ATT-applications;
3. level of inter-application influences on the impacts due to the simultaneous implementation and operation of the ATT-tools and applications in DACCORD.

The evaluation process for the integrated DACCORD-systems aims to indicate both the overall performance of the systems, and the gain (or loss) in performance due to synergy of these subsystems. The latter goal is to be achieved by a before- and after analysis of the different indicators described in the previous chapters. In this case, the candidate systems chosen are the candidate systems at different levels of integration (e.g. integration of tools and applications at the data-collection level, or integration at the central control level).

9.5.1.2. Integration

Generally speaking, a definition of integration in the present context is the following:

"the use of common resources, e.g. equipment, data, models, storage media, or human skills."

In the context of DACCORD the following levels of integration are relevant:

1. no integration: the no integration level describes a transportation system where two or more isolated ATT-applications are (competitively) active, but do not share any common resources while operating;
2. integration of data sources: the integration of data-sources indicates the integration of data from e.g. inductive loops, CCTV, weather bureau’s (short-term forecasts of weather conditions), information provided by the police, predictions of traffic conditions on neighbouring networks provided by remote traffic control centres. A requirement for this level of integration is the availability of these types of data in a same, or at least compatible format;
3. integration at the data acquisition and data storage level: common data is collected and stored by compatible facilities. Integration of data acquisition and storage ensures the running of the system on a common information base;

4. integration at the data processing level: this level of integration assures that the current estimated and predicted traffic conditions are determined by the same facilities for all ATT-applications;

5. integration at the central control level (co-ordination): integration at the control-level ensures the comparability of the implemented control strategies for co-ordinated tools and applications. Additionally, conceivable synergetic effects caused by 'compatitive' tools or applications are taken into account, and resulting impacts are optimised if applicable;

6. integration at the message distribution level: the messages distributed to the road-users are chosen from a predetermined set for all media in which comparability is necessary.

On the one hand, the advantages of integration are in general cost-reduction by avoiding the design and implementation of overlapping functions, and improved consistency due to the use of common data and models. On the other hand, integration can lead to complex systems and necessitates a clear view on the systems' architecture.

The evaluation phase in DACCORD aims to assess the different traffic control systems at the relevant level of integration.

9.5.2. Basic Approaches to the Assessment of Integrated ATT-Systems

In this section, three different approaches are proposed to assess the improved or degraded operational effectiveness due to integration.

9.5.2.1. Approach I: Overall Performance and Comparison between Isolated and Integrated ATT-Systems

In this straightforward approach, the integrated system is evaluated using indicators that permit meaningful comparisons between the isolated ATT-applications in DACCORD, and the different levels of integration implemented in the distinct DACCORD test-sites in the duration of the DACCORD programme. The approach allows for the assessment of the gain or loss in performance due to integration at the distinct levels in comparison to the isolated systems.

For this overall performance comparison, two levels of computation can be identified. These are described in the following sections.

Level 1: Computations of Values for both Isolated and Integrated Systems

The different indicators defined in the previous chapters quantifying the impacts on efficiency of the transportation systems can be used directly to assess the improvements or degradation of the efficiency of the transportation system due to integration. Hence both the common indicators relevant for both the isolated and integrated systems, i.e.:

Common Indicators

- Compliance Rate (CR);

Additionally, the indicators according to functions, which are also relevant for both isolated and integrated systems, are listed below:
**Indicators according to Functions**

- Instantaneous Travel Time (\(iTT\));
- Actual Travel Time (\(aTT\));
- Travel Time Loss (\(W\));
- Cumulative Travel Time Losses (\(cumW\));
- Mean Speed (\(V\));
- Performance (\(P\));
- Traffic Flow Rate (\(q\));
- Speed Variance (\(sV\));
- Hindering Factor (\(HindF\));
- Splitting Proportions at a Diverge (\(SP\));
- Difference between Mean Speed and Recommended Speed (\(\Delta V\));
- Lance Usage Ratio (\(LUR\));
- Capacity (\(C\));
- Maximum Performance (\(MP\));
- Total Queue Length (\(qQL\));
- Total Queue Weight (\(qQW\));
- Number of Vehicles (\(n\));
- Congestion Probability (\(Cprob\));
- Accident Rates (\(ArF, ArS, ArL\));
- Accident Damage (\(DamAcc\));
- Fuel Consumption (\(FC\));
- Exhaust Gas Emission (\(EGE\)).

are to determined for the distinct isolated and integrated systems.

**Level 2: Evaluation of the Improvement**

The evaluation of the improvement due to integration simply consist of determination (relative) improvement or degradation in the identified performance indicators, using the different techniques and assessment tools described in the first part of this chapter. Thereby, the changes due to integration at specific levels is determined.

**9.6. Impacts of Individual Applications in a Integrated Environment**

**9.6.1. Introduction**

This section on the impact assessment of integrated ATT-applications deals primarily with the assessment of the effects and impacts caused by the isolated DACCORD applications, in an integrated environment.
To this end, three approaches are presented. The first approach is the so-called *meta-analysis*, providing a straightforward tool for the statistical integration of the results from independent studies. Using this tool, effects caused by specific ATT-applications can be induced from summary results of different studies.

The second approach is computationally more demanding, but gives more statistically significant results. It involves multi-level analysis of variance, comparing raw-data from the different evaluation studies.

Finally, the second approach is the application of so-called *derived indicators*, which basically comprise extensive models of the traffic process being assessed. By calibrating these models using real-life traffic counts and speeds, the impact of the individual applications can be estimated.

9.6.2. Meta-Analysis

Meta-analysis generally refers to the statistical integration of the results from independent studies. These studies can either be performed at one distinct DACCORD site, featuring distinct sets of operational ATT-applications and a specific level of integration, or they can be performed at different sites. Essentially, meta-analysis is the statistical analysis of the summary findings of empirical studies.

For DACCORD, meta-analysis will be performed to provide for

- integration of results from one-site assessment studies for different implementation stages, e.g.:
  - *stage 0 implementation* (the current level): different ATT-applications have already been implemented, while the system has been in operation for some time;
  - *stage 1 implementation* (planned level'): the current transportation system has been extended with additional VMS-signs, ramp-metering installations etc.;
  - *stage 2 implementation* (planned level"'): the current transportation system has been extended even further, while a higher level of integration for control (co-ordination) has been attained;

- integration of results from assessment studies at the distinct DACCORD sites.

Special techniques have been developed especially for meta-analysis, due to the fact that:

1. summary data are being analysed;
2. the data may not be based on the same metric.

In DACCORD, a number of studies — at least two: *verification* and *demonstration* — are conducted, with a number of different ATT-applications implemented at the different DACCORD sites. For example, suppose that at the three DACCORD sites, both verification and demonstration studies have been conducted, and that measurement results are available for different systems implemented across the sites (see table). Assume that the measure of effectiveness are the *cumulative time losses* aggregated over the entire morning-rush hours (see 9.4). Subsequently, a data-matrix can be constructed, relating the common ATT-applications at the sites.
Table 39: Example Overview of Studies carried at different Test-Sites

<table>
<thead>
<tr>
<th>Study</th>
<th>Isolated Ramp-metering and Dynamic Route Information provision</th>
<th>Co-ordinated Ramp-metering and Dynamic Route Information</th>
<th>Co-ordinated Ramp-metering and Dynamic Route Information</th>
<th>Co-ordinated Ramp-metering, and mainline metering + route information</th>
<th>Co-ordinated Ramp-metering, and mainline metering + route guidance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verification</td>
<td>Amsterdam</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Demonstration</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Verification</td>
<td>Paris</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Demonstration</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Verification</td>
<td>Padua-Venice</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Demonstration</td>
<td></td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

The matrix of data is sparse, meaning not all studies were carried out at either the verification or demonstration stage, at all distinct test-sites. The data are average values of the cumulative travel time losses in the morning peak-hour, collected for different systems, with different network-geometrics, traffic-demand characteristics, freeway geometrics, weather conditions, freeway traffic flow- and driver characteristics.

The so-called 'parametric techniques', such as analysis of variance outlined in the previous sections, are generally more powerful: they are more likely to find statistically significant results than non-parametric techniques, such as meta-analysis. Hence if the data are comparable, use the same metric, then a parametric technique is preferred. There are 'special' techniques for meta-analysis to be applied when the data and/or the matrix of studies and scenarios so dictate.

On the other hand, is data are not comparable, e.g. when using third-party evaluation study-results, the meta-analysis approach provides a computationally low-demanding tool, enabling incorporation of these results.

9.6.3. Multi-Level Analysis of Variance

If the 'raw' data values are available and comparable, multi-level analysis techniques can be applied. These techniques are a special form of hierarchic analysis of variance.

9.6.4. Description of the Model for the Assessment of Individual ATT-Applications in a Integrated Environment

In this section, the use of derived indicators for the assessment of the effects of the individual ATT-applications in a integrated ATT-system, where both negative and positive synergetic effects are present, is explained. To this end, a specific structure of a model describing the distinct factors within a transportation system, is used as a mains to exemplify the ideas proposed.

This technique still needs extensive research. Moreover, the example described in the ensuing text does not aim to lay the foundations for the developed model.

9.6.4.1. Outline of the Model

The model aims to simulate both individual route- and departure-time choices, and trip-performance, for an integrated ATT-tools and applications transportation system, such as the transportation at the distinct DACCORD-sites. Such a model can be a
powerful tool for the assessment of individual ATT-applications is an integrated environment.

The system is characterised by the presence of the following ATT-applications:
1. dynamic route information provision (descriptive information);
2. dynamic route guidance (prescriptive information);
3. ramp-metering;
4. mainline-metering;
5. speed regulation;
6. lane-usage control.

The impact of the different ATT-applications will be experienced on different levels of the process described by the model, that is:
1. the pre-trip (global) route-choice process of the road-users;
2. the en-trip sub-route-choice process of the road-users at the different bifurcation points present in the transportation network;
3. the localised area-control (point-) process, or merging behaviour process;
4. the section-flow control process, or freeway driving behaviour process.

The different ATT-application will operate at one or more of these levels, either directly (due to the control- or information provision process), or indirectly (by changing the experiences and habits of the road-users, see Figure 25).
Co-ordinated Traffic Control in Freeway Corridors: a proposed evaluation approach

Date 26 May, 1997

Figure 25: Conceptual Model for Determination of derived Indicators

Note that the provision of pre-trip information is not an ATT-application present within the DACCORD framework. Moreover, it is implicitly assumed that the effects of such information provision are either negligible, or are known a priori.

From the pre-trip evaluation process, a departure time, and a pre-trip route choice results from evaluation of the provided pre-trip evaluation, and the expectations and habits of the road-user. For the transportation network under consideration, this implies that the OD-flows are principally determined after this stage.

However, when the road-user enters the network, he may receive additional information on the conditions of the transportation system, which may move him to change his pre-trip route-choice en-route. This is modelled in the en-route sub-route choice process.

An similar approach has been taken in [19]. However, this approach is not directly applicable for the assessment of the DACCORD applications and tools, since:

- only the impact of either prescriptive or descriptive information is accounted for. For the application of this model to DACCORD, the impact of ramp-, and mainline-metering, and section control need to be accounted for as well;
- model results are based on extensive study of just one OD-pair, using structured questionnaires for four waves of road-users. Extensive studies using structured questionnaires are unfeasible in the DACCORD programme, due to...
the necessary extent of the number of interview necessary to cover all relevant OD-relations for the different DACCORD test-sites, and the limited resources available for evaluation. At this moment, the feasibility of using other information sources is being assessed. Alternatively, additional modelling (similar to e.g. [20]) is necessary.

The evaluation manager considers to develop assessment tools for the assessment of both the impacts of the individual applications, influenced by the relevant level of integration of DACCORD tools and applications. For implementation of these assessment tools, the results of other studies can be used, e.g. the result of assessment of the direct impacts of the applications (stimuli-response) can be used to model the effect of information provision.

9.7. Validation objectives and Performance Indicators

9.7.1. Introduction
In this section, tables connecting the validation objectives previously proposed to the indicators of performance are given for each relevant ATT-application. As has been mentioned earlier, only applications having a direct impact on the transportation system are studied. Indirect impacts caused by improved state estimation are analyses by assessment of integration of the applications at various levels.

9.7.2. Verification and Demonstration
Regarding impact assessment, verification the different applications involves either (relatively small-scale) real-life measurement, or the application of simulation models (Statistical Traffic Model, Behavioural Traffic Model, METACOR).

If real-life studies are used for verification, a relatively small-scale impact assessment suffices to establish the likely impacts of the ATT-applications. In the demonstration phase of the evaluation, statistically significant evidence can be established, by using sample-sizes which can be expected to provide for these statistically significant results (based on variance-estimates from the verification stage).

If simulation-tools are used for verification, the simulation tool itself induces additional unreliability in the verification results. Hence, the simulation tool needs to be or have been calibrated carefully and extensively, and the simulation tool itself needs to be validated. If the tools passes validation successfully, simulation may provide the likely impacts of the ATT-applications, thereby providing indicating that the demonstration provides statistical evidence of the successfulness of the applications.

9.7.3. Tables depicting the connection between Validation objectives, and Performance Indicators; Overall Definition of Success
In the following tables, the completion of the impact assessment plan is given: the validation objectives are linked to the respective performance indicators, and an overall definition of success ("when is the validation objective reached?") is identified.
On the one hand, some tools for assessment are used in order to decide on the overall success of all validation objectives. These tools are:

- time series analysis of sample mean, sample variances, and sample median, using blocking with respect to time of day (fifteen minutes; morning, evening rush hour, and off-peak periods), to assess to which extent the implementation is a success (remember the “overall definition of success”) at a specific level of significance, depending on the phase of assessment (verification, simulated verification, or demonstration);

- analysis of variance (one-, and many-way) to contemplate the significance of the hypotheses (p-value). Note that usually, the zero-hypotheses is defined by:

  \[ H_0: \text{difference before-after} = \text{overall definition of success threshold} \]

- regression analysis to enable the analysis of hypotheses, irrespective of distinct disturbances of the traffic process;

- meta-analysis;

- hierarchical analysis of variance techniques;

- method of derived indicators.

On the other hand, some tools are assessment objective- and application-specific:

- stimuli-response techniques to assess the direct effects on the transportation systems caused by implementation of the application;

Use of these tools will be indicated in the tables following.
**DACCORD Application** | **Validation objective to establish:** | **Performance Indicators** | **Overall Definition of Success**<sup>16</sup> |
---|---|---|---|
**Section-Level Traffic Control (speed regulation and lane usage control)** | | | |
- level of effectiveness of the ATT-applications as a means to control traffic by analysis of compliance rate of route users, i.e.:  
  - level of change in average speed with respect to recommended speed;  
  - compliance to lane-use control settings | $\Delta V, V_{\text{rec}}$  
LUR | $\Delta V/V_{\text{rec}} < 1.2$  
LUR < 90% |
- level of change in effective road-capacity of a section, due to improved use of infrastructural facilities | $C_s$  
P, MP  
Cprob  
$QL$  
$IQW$  
$\text{cumW}$ | increase $C_s > 2\%$  
increase $P/MP > 2\%$  
decrease $C\text{prob} > 5\%$  
decrease $QL > 5\%$  
decrease $IQW > 5\%$  
decrease $\text{cumW} > 2\%$ |
- level of change in frequency and severity of congestion due to improvements in the effective road-capacity | $W$  
iTTS  
$aTTS$  
$C_s$ | decrease $W > 2\%$  
decrease iTTS $> 2\%$  
decrease $aTTS > 2\%$ |
- the level of change in the number of reported accidents and incidents  
the level of change in the impedance of the road-user | $ArF, ArS, ArL$  
sV  
$\text{HindFs}$ | decrease $ArF, ArS, ArL > 10\%$  
decrease $sV > 10\%$  
decrease $\text{HindFs} > 10\%$ |
- level of change in the variability of travel times and travel time losses | $aTT$  
$W$ | decrease var$(aTT) > 5\%$  
decrease var$(W) > 5\%$ |
- level of change in exhaust gas emissions due to implementation of the application  
level of change in fuel consumption due to implementation of the application | $\text{EGE}$  
$\text{FC}$ | decrease $\text{EGE} > 2\%$  
decrease $\text{FC} > 2\%$ |

---

<sup>16</sup>The definition of success is established at a 80% for real-life verification, or 90% significance level at the simulated verification, or demonstration phase. Additionally, one-way or many way analysis techniques are used to establish statistical differences between the before and after study.
<table>
<thead>
<tr>
<th>DACCORD Application</th>
<th>Validation objective to establish:</th>
<th>Performance Indicators</th>
<th>Overall Definition of Success</th>
</tr>
</thead>
</table>
| Point Control (ramp- and mainline-metering) | • level of effectiveness of the ATT-applications as a means to control traffic by analysis of compliance rate of route users, i.e.:  
   a compliance to the ramp-metering and mainline-metering policies | GR, RLDr | GR > 80%;  
   RLDr < 20% |
| | • level of change in effective road-capacity of a section, due to peak-shaving effects | Cg, P, MP, Cprob, QQL, IQW, cumW, SP | increase Cg > 2%;  
   increase P/MP > 2%;  
   decrease Cprob > 5%;  
   decrease tQL > 5%;  
   decrease tQW > 5%;  
   decrease cumW > 2%;  
   change in SP > 5% |
| | • level of change in the frequency and severity of congestion due to:  
   a changes in traffic demand due to re-routed drivers  
   b avoidance of congestion by re-routed road-users | W, iTTS, aTTS, Cg, SP | decrease W > 2% while  
   decrease iTTS > 2%;  
   decrease aTTS > 2% |
| | • the level of change in the number of reported accidents and incidents | ArF, ArS, ArL, sV, HindFs | decrease ArF, ArS, ArL > 5%;  
   decrease sV > 5%;  
   decrease HindFs > 5% |
| | • the level of change in the impedance of the road-user | iTT, aTT, W, Cprob | decrease var(iTT) > 5%;  
   decrease var(aTT) > 5%;  
   decrease var(W) > 5%;  
   decrease Cprob > 5% |
| | • level of change in exhaust gas emissions due to implementation of the application | EGE, FC | decrease EGE > 2%;  
   decrease FC > 2% |
| | • level of change in fuel consumption due to implementation of the application | | |

---

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<table>
<thead>
<tr>
<th>DACCORD Application</th>
<th>Validation objective to establish</th>
<th>Performance Indicators</th>
<th>Overall Definition of Success</th>
</tr>
</thead>
</table>
| Network Control (travel time display, queue length display, and route guidance) | - level of effectiveness of the ATT-applications as a means to control traffic by analysis of compliance rate of route users, i.e.: 
  a road-users response to information on travel times/queue lengths provided by the VMS 
  b compliance rate of road-user to road-guidance | SP | change in SP > 5% 
  - Stimuli-Response techniques are applied in order to assess the direct effects of information provision (prescriptive or descriptive) |
|                      | - level of change in the frequency and severity of congestion due to: 
  a changes in traffic demand due to re-routed drivers 
  b avoidance of congestion by re-routed road-users | Cprob, tQL, tQW, cumW, SP | decrease Cprob > 2% 
  decrease tQL > 5% 
  decrease tQW > 5% 
  decrease cumW > 5% |
|                      | - level of change in travel time losses due to changes in the frequency and severity of congestion caused by decreased traffic demand due to re-routed drivers 
  - level of change in travel time losses due to congestion by avoidance of congestion by re-routed road-users | W, iTTS, aTTs, SP | decrease W > 2% 
  decrease iTTS > 2% 
  decrease aTTs > 2% |
|                      | - the level of change in the number of reported accidents and incidents 
  - the level of change in the impedance of the road-user | ArF, ArS, ArL, sV, HindFp | decrease ArF, ArS, ArL > 10% 
  decrease sV > 10% 
  decrease HindFp > 10% |
|                      | - level of change in the variability of travel times and travel time losses due to: 
  a changed traffic demand due to re-routed drivers 
  b avoidance of congestion for re-routed drivers | iTT, aTT, W, Cprob | decrease var(iTT) > 5% 
  decrease var(aTT) > 5% 
  decrease var(W) > 5% 
  decrease Cprob > 5% |
|                      | - level of change in exhaust gas emissions due to implementation of the application 
  - level of change in fuel consumption due to implementation of the application | EGE, FC | decrease EGE > 2% 
  decrease FC > 2% |
### DACCORD Application

#### Integration of applications at control level (CJTMS, or OSS-systems)

**Validation objective to establish:**
- level of change in the frequency and severity of congestion due to improved network capacity caused by reduction of synergetic effects of isolated ATT-applications, improved re-routing, etc.

**Performance Indicators:**
- C
- P, MP
- Cprob
- IQL
- IQW
- cumW
- SP

**Overall Definition of Success:**
- increase C > 2%
- increase P/MP > 2%
- decrease Cprob > 2%
- decrease IQL > 5%
- decrease IQW > 5%
- decrease cumW > 2%
- change in SP > 5%

- level of change in travel time losses due to changes in the frequency and severity of congestion caused by improved network capacity caused by reduction of synergetic effects of isolated ATT-applications, improved re-routing, etc.

**Performance Indicators:**
- W
- iTTS
- aTTS
- C
- SP

**Overall Definition of Success:**
- decrease W > 2%
- decrease iTTS > 2%
- decrease aTTS > 2%

- the level of change in the number of reported accidents and incidents
- the level of change in the impedance of the road-user

**Performance Indicators:**
- ArF, ArS, ArL
- sV
- HindFs

**Overall Definition of Success:**
- decrease ArF, ArS, ArL > 10%
- decrease sV > 10%
- decrease HindFs > 10%

- level of change in the variability of travel times and travel time losses due to:
  - changed traffic demand due to re-routed drivers
  - avoidance of congestion for re-routed drivers

**Performance Indicators:**
- iTT
- aTT
- W
- Cprob

**Overall Definition of Success:**
- decrease vari(iTT) > 5%
- decrease vari(aTT) > 5%
- decrease vari(W) > 5%
- decrease Cprob > 5%

- level of change in exhaust gas emissions due to implementation of the application
- level of change in fuel consumption due to implementation of the application

**Performance Indicators:**
- EGE
- FC

**Overall Definition of Success:**
- decrease EGE > 2%
- decrease FC > 2%

### Table 40: Experimental Set-Up for Impact Assessment

### 9.8. Interpretation of Results

An important step in assessment is the interpretation of results. For the results to be believable, and to be able to stand up to inspection, the basic assumptions underlying the analytical technique must not have been significantly violated.

Perhaps the expected changes due to the transport telematics implementation have not been realised. Were there other changes during the study period which might have reduced the impact? Should other variables be checked for change, such as traffic flow rates, the weather, etc.? This is the time to check that the study design and analysis were not compromised, or confounded by other effects.

Was the achieved sample size smaller than intended, or was the spread of the sample data greater than expected? These factors will affect the effectiveness of the study to detect any changes on impact variables. If the answer to either question is yes then it would be useful to calculate the actual size of difference detectable at say the 95% level using the actual sample.
10. **EXPERIMENTAL SET-UP (4): SOCIO-ECONOMIC ASSESSMENT**

After impact-assessment has taken place, socio-economic assessment can performed. In the following chapter, socio-economic assessment for DACCORD ATT-applications is described. The evaluation method can be performed based on the results of the impact assessment, and on the values of additional performance indicators, presented in previous chapters. To this end, the following definition of socio-economic assessment is used:

*Socio-Economic Assessment* “estimating the social and economical gains or losses as a result of implementation of an ATT-application.”

### 10.1. Socio-Economic Assessment in DACCORD

In the following paragraphs, the experimental plan for the economic evaluation within the DACCORD programme is presented.

**10.1.1. General Aim of Socio-Economic Assessment**

Socio-Economic evaluation aims to estimate the 'social' gains or losses (the global economic gains and losses, for all members of society) as the result of implementation of the different DACCORD ATT-applications in comparison with the existing situation. Additionally, comparison between the different DACCORD sites is possible. Moreover, inter-application comparison provides additional insight on the economical functioning of the ATT-applications.

The social gains (or losses) are assessed using appropriate indicators, certainly including direct and indirect costs and benefits, but also non-monetary factors if those are affected significantly by the application under study.

Depending on the technical approach, there are two principal types of socio-economic evaluation methods: cost-benefit analysis and multicriteria analysis. Principally, cost-benefit analysis is performed in DACCORD.

**10.1.2. Cost and Benefits of the DACCORD ATT-applications**

In this subsection, the (monetary) costs and benefits of general DACCORD ATT-applications are presented. In the economical assessment, care should be taken that all costs and benefits resulting from the implementation and running of the applications, are accounted for, and are accounted for only once. To facilitate consequent analysis, only the costs and benefits of the network-, and system-operators, the road-users, and the victims are taken into consideration. This simplification is justifiable, since the costs and benefits experienced by the user-group policy makers, are reflected in the costs and benefits of the former user-groups. For example, the direct costs for equipment are reflected by cost of equipment paid for by the network-operators. However, the policy makers initially fund the network-operators. Hence, the cost of equipment directly endured by the
network operator, is indirectly endured by the policy makers. However, for economic evaluation, this distinction is impractical.

The (monetary) costs and benefits for the network-, and system-operators, the road-users, and the victims, are reflected in the following figure:

![Diagram showing expected benefits from ATT-applications relevant for economic assessment.](image)

<table>
<thead>
<tr>
<th>road-users</th>
<th>network-/system operators</th>
<th>non-road users</th>
</tr>
</thead>
</table>
| travel time reduction | increase in network efficiency:  
- vehicles per hour  
- reduction of traffic jams | reduction in level of pollution:  
- emissions |
| travel distance reduction | increase in safety:  
- number of accidents  
- number of people injured  
- number of people killed | |
| reduction in operating cost of vehicles | increase in toll revenues | |
| safety | | |

Figure 26: Scheme depicting relevant Cost and Benefits

Additionally, the following table illustrates the breakdown of the different costs and benefits into different performance indicators defined earlier.
When considering the different indicators proposed to be relevant for socio-economic assessment, additional assumptions need to be made concerning road-user/vehicle composition, i.e. what fraction of road-users at a specific time of day is of the 'working' or 'non-working'-type, and what fraction of traffic belongs to the passenger car, bus, light-, or heavy-truck vehicle class. Additionally, estimates need to be made on the composition of the air polluted by the vehicles.

In Table 41, conversion rates from the values of the performance indicators to ECU are given (see [16]).
### Costs

<table>
<thead>
<tr>
<th>Costs</th>
<th>Cost of Equipment</th>
<th>Cost of Operation</th>
<th>market-prices</th>
<th>market-prices, labour-rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>working persons</td>
<td>pure travel time</td>
<td>17.0</td>
<td>ECU/pers/hr.</td>
<td>ECU 'equity' values</td>
</tr>
<tr>
<td>non-working pers.</td>
<td>pure travel time</td>
<td>4.3</td>
<td>ECU/pers/hr.</td>
<td>(estimated) resource costs</td>
</tr>
<tr>
<td>vehicles</td>
<td>passenger cars</td>
<td>0.8</td>
<td>ECU/veh/hr.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>busses</td>
<td>7.9</td>
<td>ECU/veh/hr.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>light trucks (lorries)</td>
<td>3.1</td>
<td>ECU/veh/hr.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>heavy trucks (coupled)</td>
<td>4.9</td>
<td>ECU/veh/hr.</td>
<td></td>
</tr>
<tr>
<td>Veh. Op. Cost</td>
<td>distance dep.</td>
<td>passenger cars</td>
<td>0.09</td>
<td>ECU/veh.km.</td>
</tr>
<tr>
<td></td>
<td>busses</td>
<td>0.45</td>
<td>ECU/veh.km.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>light trucks (lorries)</td>
<td>0.14</td>
<td>ECU/veh.km.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>heavy trucks (coupled)</td>
<td>0.27</td>
<td>ECU/veh.km.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fuel consumption</td>
<td>0.36</td>
<td>ECU/l</td>
<td>market prices (corr.)</td>
</tr>
<tr>
<td>Safety</td>
<td>fatalities</td>
<td>744.17</td>
<td>ECU/pers.</td>
<td>ECU 'equity' values</td>
</tr>
<tr>
<td></td>
<td>seriously injured</td>
<td>105.59</td>
<td>ECU/pers.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>slightly injured</td>
<td>7.080</td>
<td>ECU/pers.</td>
<td>resource costs</td>
</tr>
<tr>
<td></td>
<td>material damage</td>
<td>1</td>
<td>ECU</td>
<td></td>
</tr>
<tr>
<td>Air Pollution</td>
<td>carbon monoxide</td>
<td>3</td>
<td>ECU/t</td>
<td>EC adjusted values</td>
</tr>
<tr>
<td></td>
<td>nitrogen oxides</td>
<td>445</td>
<td>ECU/t</td>
<td></td>
</tr>
<tr>
<td></td>
<td>hydrocarbons</td>
<td>348</td>
<td>ECU/t</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sulphur dioxide</td>
<td>240</td>
<td>ECU/t</td>
<td></td>
</tr>
<tr>
<td></td>
<td>lead</td>
<td>16,902</td>
<td>ECU/t</td>
<td></td>
</tr>
<tr>
<td></td>
<td>particles</td>
<td>227</td>
<td>ECU/t</td>
<td></td>
</tr>
</tbody>
</table>

**Table 41: Proposed Values to convert Units of Indicators into ECU (source: EVA, Munich December 1991)**

### 10.1.3. Cost-benefit analysis

Using cost-benefit analysis, the ration (or difference) between the benefits and the costs of an ATT-application. The analysis considers a specific time horizon and spatial dimension. The time horizon chosen for the DACCORD ATT-applications is a decision-variable: leaving the time horizon 'free' enables estimating the time horizon in which an ATT-application becomes profitable. The spatial dimension is pre-determined by the spatial dimensions of the networks of the different DACCORD sites (see description of test-sites in DACCORD).

Both benefits and costs incurred in future years are 'discounted' by an appropriate discount rate \( r \). The benefit-cost ratio \( RBC \) can thus be expressed as follows:

\[
RBC = \sum_{y=\gamma}^{Y} \frac{B(y) \cdot (1 + r)^{-(y-y_0)}}{C(y) \cdot (1 + r)^{-(y-y_0)}}
\]

where \( y \) denotes the year, \( y_0 \) and \( Y \) denote the starting year, and the time horizon respectively, and \( B(y) \), and \( C(y) \) denote the (expected) monetary benefits and costs in year \( y \). Alternatively, the difference \( DBC \) can be defined:
Cost-benefit analysis uses money as the only unit of account. That means that both cost and benefit must be measured or converted into a monetary unit, e.g. ECU, to enable a direct comparison of costs and benefits related to a proposed implementation (see Table 41).

The minimum requirement for an investment in the candidate system is usually:

\[ RBC > 1 \]

(or \( DBC > 0 \)). In comparing alternatives the one with the greatest \( RBC \) (or \( DBC \)) would usually be selected for implementation.

Additionally, sensitivity-tests are performed: by changing the different values of the concerned impacts (travel time, travelled distance), the susceptibility of the \( RBC \)-value to minor changes in the effects due to implementation of the application is determined. The sensitivity can be used in order to determine the reliability of conclusions drawn from the \( RBC \)-value.
11. TERMINOLOGY AND DEFINITIONS USED

**Application:** a telematics system or service as installed and operating in a real-life environment.

**Assessment:** the process of determining the performance and/or impacts of an application, usually in comparison to a reference case (existing situation or alternative applications), and (usually) based on real-life or other experiments, often involving users.

**Assessment Category:** a collection of assessment methods, dealing with same of similar assessment objectives.

**Assessment Objectives:** general criterion used by the main decision makers at different levels for making judgements about the system being assessed.

**Co-ordination:** integration at the (central) control level.

**Decision makers:** those responsible for the production, the introduction, and/or the implementation of the ATT application, e.g. governmental agencies (local, national, European), or system providers.

**Demonstration:** the second stage of validation. It is conducted under operational conditions. It concentrates on acceptance of the application by a larger sample of end-users and comprehensive impact analyses in order to evaluate the benefits of the application.

**Evaluation:** the process of (1) determining the value of an application in comparison to alternative applications and/or to a 'base case' and (2) deriving recommendations for decision makers based on identified requirements and (3) analysing results of related experiments.

**Extendibility:** the potential for extending the control system by additional parts of the network, or additional ATT-applications.

**Field Trials:** an organised trial of an application in a real or controlled environment, based on related evaluation requirements.

**Flexibility:** the ability to adjust the application's objectives and constraints after implementation of the application.

**Functional Architecture:** the Functional Architecture addresses the functional behaviour of the Central Traffic Management Systems. In other words, it addresses how the systems operate in terms of the main independent processes, and their logical flow of information between those processes. By its definition, a Functional Architecture distinguishes itself from the design and realisation domains, that describe how the Central Traffic Management System will be implemented.

**Impacts:** changes or effects brought about by an application resulting from its implementation in an experimental or real application.
Impact Assessment: the measurement or estimation of the effects of a candidate ATT-tool, for example the impacts on safety, environmental conditions, or efficiency of the transportation system, with respect to the target user-groups likely to be affected.

Indicators: variables, directly measured or derived from measurements or modelling, indicating the performance or impacts of an application.

Integration: the use of common resources, e.g. equipment, data, models, storage media, or human skills.

Intersection: part of the road-network where traffic streams split or merge.

Measurement Block: a measurement block is a defined environment for a measurement, in which conditions which could influence the indicators investigated should be kept as constant as possible.

Network: part of the road-network for which one unit of traffic management is responsible for direct management activities.

Network Operators: the managers of the network, having a medium term perspective, aiming to translate policies into practical plans and study programmes, and thus provide a cost-effective, safe and efficient road network system.

Policy Makers: public authorities (either local regional, national, or international) having a long term perspective, aiming to provide a cost-effective, safe and efficient transportation system.

Pre-Assessment: the process of determining the expected impacts of a tool or application and the approximate magnitude of these expected impacts.

Reference Case: the performance of the application as measured by the indicators must be compared against a 'reference case.' Standards are commonly used for testing the physical functioning of the application. The reference case is usually a current application or current way of doing things for testing user acceptance, conducting impact analyses and evaluating benefits.

Section: homogeneous part of the road-network between intersections (merges, diverges, or other localised areas).

Socio-Economic Assessment: estimating the social and economical gains or losses as a result of implementation of an ATT-application.

Synergy: the way the effects of the simultaneous utilisation of the ATT-tools and applications compare to the sum of separate effects.

System Operators: the crew managing the road traffic on a day-to-day basis at the distinct sites, aiming to run a safe and efficient network, using the facilities provided by the network operators.

Technical Assessment: the process of determining the extent in which technical requirements are met.

Users: the humans on whose behalf the system is developed.
User Acceptance Analysis: the process of estimating users’ attitudes to and perception of the separate ATT-applications.

User Group: a user group is identifiable group of individuals affected by the telematics application directly, or indirectly, utilising the telematics application directly, indirectly or not at all.

Validation: validation is the process of testing how an application performs with respect to the assessment objectives.

Value function: function to convert measured or derived quantities into a (one-dimensional) unit of evaluation.

Verification: the first stage of validation is termed ‘verification.’ It is not conducted under operational conditions. It concerns testing the physical functioning of the application and acceptance of the application by its main sponsors. Additionally, it may be necessary to conduct preliminary tests of user acceptance by other end-users.

Weights: parameters indicating the relative importance of evaluation objectives.
12. REFERENCES


[18] Gruebel, *College notes for the course “a82c: Advanced Statistics”*, Delft University of Technology, Department of Mathematical Engineering, 1991


### ACRONYMS AND ABBREVIATIONS

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANIMATE</td>
<td>Added Support to Strategy, Cohesion, and Dissemination for Transport and Environmental Projects</td>
</tr>
<tr>
<td>ATT</td>
<td>Advanced Transport Telematics</td>
</tr>
<tr>
<td>BTM</td>
<td>Behavioural Traffic Model</td>
</tr>
<tr>
<td>CCTV</td>
<td>Closed Circuit Television systems</td>
</tr>
<tr>
<td>CODE</td>
<td>Co-Ordinated Dissemination in Europe of Transport Telematics achievements</td>
</tr>
<tr>
<td>CONVERGE</td>
<td>Telematics Sector Consensus and Support</td>
</tr>
<tr>
<td>CORD</td>
<td>Co-ordination Of Research and Development (part of the DRIVE II project)</td>
</tr>
<tr>
<td>CTMS</td>
<td>Central Traffic Control System</td>
</tr>
<tr>
<td>DACCORD</td>
<td>Development and Application of Co-ordinated Control of Corridors</td>
</tr>
<tr>
<td>DTM</td>
<td>Dynamic Traffic Management</td>
</tr>
<tr>
<td>GERDIEN</td>
<td>General European Road Data Information Exchange Network</td>
</tr>
<tr>
<td>METACOR</td>
<td>Macroscopic Modelling Tool for Urban Corridors</td>
</tr>
<tr>
<td>RWS-AVV</td>
<td>the Ministry of Transport, Research Centre</td>
</tr>
<tr>
<td>RWS-NH</td>
<td>the Ministry of Transport, Regional Directorate North-Holland</td>
</tr>
<tr>
<td>SATIN</td>
<td>System Architecture and Traffic control Integration (task force in the DRIVE II project)</td>
</tr>
<tr>
<td>STM</td>
<td>Statistical Traffic Model</td>
</tr>
<tr>
<td>TCC</td>
<td>Traffic Control Centre</td>
</tr>
<tr>
<td>TIC</td>
<td>Traffic Information Centre</td>
</tr>
<tr>
<td>TRAC</td>
<td>Traffic, Road surface and Ambient Conditions</td>
</tr>
<tr>
<td>VMS</td>
<td>Variable Message Sign</td>
</tr>
<tr>
<td>VDS</td>
<td>Variable Direction Sign</td>
</tr>
</tbody>
</table>
De sectie Verkeerskunde houdt zich bezig met onderwijs en onderzoek op het gebied van planning, ontwerp en exploitatie van goederen, alsmede het functioneel ontwerp van verkeersinfrastructuur.

De sectie Verkeerskunde maakt deel uit van de Vakgroep Infrastructuur van de TU Delft, Faculteit der Civiele Techniek, en participeert in de onderzoekschool TRAIL.