

# What is required to guarantee data quality for regional traffic management?

## Implementation of traffic data quality management in the Middle Netherlands

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### Abstract

VERDER, a partnership of different governmental organizations in the Middle Netherlands, initiated different projects for regional traffic management to better use existing road capacity and safeguard mobility in the Middle Netherlands. This active form of traffic management requires traffic data with a certain quality level, although this is not taken into account in current plans. An organization plan to guarantee data quality for regional traffic management, based on various literature and expert interviews, was created and validated with experts. The plan contains a *chain manager* responsible for managing data quality through the information chains of regional traffic management and four different data management steps: define, measure, analyse and improve. The validation revealed that this plan brings substantial improvement on current practice.

**Keywords:** data quality, regional traffic management, Total Data Quality Management (TDQM)

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**Biographical Notes:** Peter (P.A.G.) Seelen BSc is a System Engineering, Policy Analysis & Management student at Delft University of Technology. This scientific paper presents the results of his graduation research.

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### 1. INTRODUCTION

Because of an increase in vehicle loss hours (Kennisinstituut voor Mobiliteitsbeleid, 2011, p. 75) VERDER, a partnership of Dutch governmental organizations, initiated different projects to safeguard mobility in the Middle Netherlands. One of those projects for the Middle Netherlands is active traffic management (ATM). This regional ATM is called regional traffic management (RTM).

An important characteristic of ATM is the dependency on data input. Based on this data, measures are taken to improve the traffic flows and optimize the utilization of road capacity. If the data quality is not up to the required level, safety systems might fail and wrong measures might be taken (Rijkswaterstaat, 2008), having economic and social consequences (Laudon, 1986; Liepins & Uppuluri, 1990).

Capgemini is a worldwide commercial company doing business in consulting, technology, outsourcing, and local professional services. In an architecture Capgemini developed for RTM, commissioned by the Province of Utrecht, data quality was just a small part of the assignment. Data quality didn't get the attention it deserves to be able to execute RTM. Therefore the aim of this article is to find out what is required to guarantee data quality for RTM.

First the methodology (2) used is explained. After some background information on ATM (3), data quality in information chains is described (4). That knowledge is combined with managerial and technical aspects (5, 6, 7) to create an organization plan (8). The article ends with conclusions and discussion (9).

## **2. METHODOLOGY**

To find out how data quality can be guaranteed in information chains of RTM, first the current situation is explored. By comparing the current situation with the desired theoretical situation, insights are generated about changes that have to be made to transform from the current to the desired situation.

The first theoretical part of data quality and information chains of RTM is mainly based on international literature, making the basis of the organization plan valid. This also provides information about relevant quality aspects. Then the theoretical knowledge is combined from a managerial and a technical perspective. Some Dutch literature is used here, however the expert interviews have a more important role. Experts that have been interviewed are from different types of organizations involved in RTM, namely road authorities and contractors. With this practical and theoretical knowledge an organization plan is created based on the methodology of total data quality management (TDQM) and validated by RTM experts.

## **3. BACKGROUND**

Before starting with the theoretical knowledge of data quality some background information about ATM, RTM and their role in the Netherlands is given. From a policy point of view, the Ministry of Transport, Public Works and Water Management (2008) developed three policy pillars to deal with the increase in vehicle loss hours as mentioned in the introduction. The first pillar focuses on building new roads to increase road capacity. Paying for road usage can be found in the second pillar, named (road) pricing. Utilization is the last pillar and has the purpose of using existing road capacity in a more optimal way.

Utilization can be realized by optimizing road capacity related to the current traffic demand, optimizing traffic flows and guiding and controlling traffic. Guiding and controlling of traffic is especially important in special situations, e.g. bad weather or accidents. On a national level in the Netherlands utilization is realized by the use of active traffic management (ATM). Rijkswaterstaat (RWS) operates from one central traffic management centre (TMC) and five region TMCs. These TMCs manage traffic on the primary road network of the Netherlands, mainly consisting of highways.

Problems indicated on a national level can also be found on a regional level in the Middle Netherlands. To (partly) solve those problems, VERDER initialised the idea of RTM for the Middle Netherlands. So what is ATM exactly? Brinckerhoff (2010) explained ATM as "...an approach for dynamically managing and controlling traffic demand and available capacity of transportation facilities, based on prevailing traffic conditions, using a combination of real-time and predictive operational strategies". Based on historical and real-time measurements optionally combined with traffic predictions, strategies existing of different measures are implemented. RTM is comparable to ATM, but the difference is the focus of ATM on the national primary road network and the focus of RTM on the regional and local road networks. On highways this can, for example, be done by closing driving lanes and giving travel advices to road users. For RTM this is for example possible by creating optimized flows in networks of traffic signals, e.g. green waves, and also by giving travel advice.

## **4. DATA QUALITY IN INFORMATION CHAINS**

The introduction made clear what the data quality problem is and the previous paragraph explained ATM/RTM and the role of it in the Netherlands. In this section, the data quality is linked to the information chains of RTM. Before explaining the information chains first data quality is dealt with.

#### 4.1. Data quality

To find out what data quality is about, data and quality are defined separately:

- **Data:** Data are ‘meaningless’ bits without extra (meta)data. By adding ‘meaning’ to these facts, they become information. Knowledge is created by applying data and information. One level higher wisdom can be derived from knowledge. (Ackoff, 1989).
- **Quality:** Juran (1988), a pioneering authority in the field of quality management, bases quality on two concepts: “fitness of use” and “a product free from deficiencies”. Quality therefore is a conditional attribute.

In literature data and information are often used interchangeably. When data is used in this article both data and information are meant, unless explicitly stated otherwise.

Knowledge and wisdom as meant by Ackoff (1989) are placed out of scope. Data and information have each their own characteristic regarding quality.

##### *Data quality*

According to the Joint Committee for Guides in Metrology (2012) and International Organization for Standardization (1994, 2006), the following data quality aspects can be identified:

- **Accuracy:** “closeness of agreement between a measured quantity value and a true quantity value of a measurand” (measurand: “quantity intended to be measured”)
- **Precision:** “closeness of agreement between indications or measured quantity values obtained by replicate measurements on the same”
- **Trueness:** “closeness of agreement between the average of an infinite number of replicate measured quantity values and a reference quantity value”

Because of the confusion between the terms trueness and precision, the difference between these two terms is visualized in figure 1: the left target (a) shows high trueness and low precision and the right target (b) shows high precision with low accuracy.

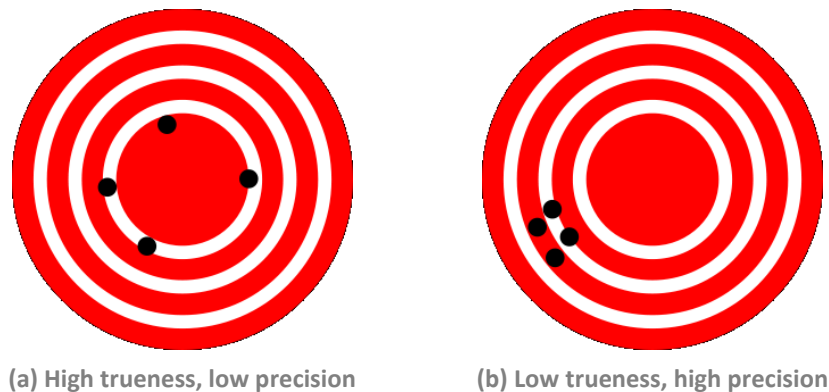


Figure 1 – Visualisation of trueness and precision

It should be mentioned that accuracy is “related to both” trueness and precision (Joint Committee for Guides in Metrology, 2012). This makes it hard to relate issues individually to just precision or trueness. To cope with this problem issues will be related to data quality as such.

##### *Information quality*

From the data definition it is clear that information is created by adding meaning to data. Therefore the data quality aspects accuracy, precision and trueness are part of information quality as well. However other aspects can be related to information quality. Some examples:

- *Completeness*: the number of entities measured over the number of total entities.
- *Presentation*: information presented should be easy to understand. No flood of information for operators.
- *Timeliness*: closeness of agreement between the point of time the information is necessary and the point of time the information is available.
- *Place*: closeness of agreement between the place the information is necessary and the place the information is available.

Having a clear definition of data quality is necessary to prevent miscommunications and make it possible to compare data and data quality. The definition should of course be shared by all the stakeholders.

#### 4.2. Information chains

Data quality for RTM is strongly related to information chains. These ‘chains’ start from the traffic measurements and end when the traffic measurement is distributed as data to the end consumer. In fact all these chains together form a network. Figure 2 gives an overview of the functionalities of the information chains, resulting in a functional information chain. Each functionality is shortly discussed.



Figure 2 – Functional information chain regional traffic management

*Measurement* is the first step in the information chain and gathers data through measurements. Measuring is done by different instruments, such as inductive loops, cameras and infrared radar. Algorithms do the first data processing by filtering bad measurements and aggregates data. Measurements can for example be aggregated every minute or every 5 minutes. *Data processing* before storage might be necessary to generate comparable data, however it is possible raw data is lost in this processing step. *Storage* of traffic data is especially necessary for evaluation of RTM measures taken or for policy evaluation of the traffic system. Depending on the type of storage and the services provided after storage data may be processed again before it is *distributed* to the information consumers. Depending on the application that uses the traffic data, different quality aspects might be of importance. Which aspect is relevant depends on the goal of the application (Wang, Kon, & Madnick, 1993). Note that data has to be *transported* between each functional step of the information chain.

#### 4.3. Current situation

NDW (Nationale Databank Wegverkeersgegevens – National Traffic Information Database) the organization responsible for traffic data storage uses four quality aspects: accuracy, reliability, availability and topicality (NDW, 2008). The data quality aspects precision and trueness are taken into account as ‘unreliability’ and ‘inaccuracy’.

The quality classifications of NDW are doubtful, since the goal of the application determines the quality requirements. While NDW sets certain requirements and, for example, sets values based on these requirements. By saving raw measurements values and its quality, data consumers can decide whether or not the measurements suit their requirements.

Interviewees of the Province of Utrecht and the municipality of Amersfoort especially mention the quality aspect timeliness (Seelen, 2012: Appendix E, Appendix F, Appendix H). One interviewee also mentioned the aspect of availability, probably because of his technical function (Seelen, 2012: Appendix G).

The interviewees of the two commercial companies seem to be more aware of the different data quality aspects. Together with the interviewee of the municipality of Amersfoort they explicitly mentioned the relation between the goal of the application and the required data and level of data quality (Seelen, 2012: Appendix H, Appendix I, Appendix J).

## 5. MANAGERIAL

As the previous paragraph indicated quite some actors are involved in the information chains of RTM, all with their own perception of data quality. This paragraph explains which actors are involved in RTM and how they are related to each other.

Within the actors involved, a distinction can be made between road authorities and other actors.

The road authorities are RWS, the Province of Utrecht and municipalities. RWS is the executive department of the Dutch Ministry of Infrastructure and Environment and “is responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands” (Rijkswaterstaat, 2011a). The main infrastructure facilities mainly exist of highways (A-ways) and some important provincial ways (N-ways) (Rijkswaterstaat, 2012). RWS measures traffic on the national road network it is responsible for. Part of the measuring is done by RWS, part of it is outsourced. Also maintenance of these systems is outsourced to other parties (Seelen, 2012: Appendix D). RWS is aware of data quality (Rijkswaterstaat, 2008), but has problems meeting availability requirements as is explained in the next paragraph. As extra aspect it can be added that measuring systems of RWS are certified before use.

The Province of Utrecht is, as a regional road authority, responsible for the management and maintenance of the road network at a lower level, mainly consisting of provincial ways. The provincial ways are the link between the national road network of RWS and the local road networks of municipalities. Goals of the province is “accessibility for everyone and safe transportation by public transport, bike, car or boat” (Province of Utrecht, 2012). Important difference between the province and RWS is the responsibility of the province regarding slow traffic such as bikes. The organization for traffic measurements is outsourced, meaning that another party is responsible for the gathering of traffic data (Seelen, 2012: Appendix E). This is also the case for the communication network and partly for other traffic systems of the province (Eurofiber, 2010).

Local roads are the responsibility of municipalities. Largest two municipalities of the Province of Utrecht are Utrecht and Amersfoort. It is assumed that smaller cities have comparable or less complex situations regarding RTM. Both Amersfoort (Municipality of Amersfoort, 2005) and Utrecht (Municipality of Utrecht, 2005) share the main goal of accessibility and the responsibility for their local road network. Municipalities have to deal with even more variety in road users compared to the province and RWS, making traffic management even more complex (Seelen, 2012: Appendix F). The municipalities don’t rely on traffic data for their current tasks and currently aren’t aware of the importance of data quality (Seelen, 2012: Appendix G, Appendix H).

Despite the fact the three road authorities have comparable policy goals, the type of traffic data and quality necessary to monitor these goals differ. This is caused by the different types of roads the authorities focus on.

Other actors are VERDER, NDW and contractors. As is clear from the introduction VERDER is a partnership of different governmental organizations. The goal of VERDER is to safeguard “mobility in the Middle Netherlands” (VERDER & Arane, 2009). Through VERDER financial resources have been reserved for RTM. Data quality should be taken into account in the current measures, otherwise new financial resources need to be obtained.

NDW can be explained in three ways. The first one is comparable to VERDER, namely a partnership of different public organizations: RWS, provinces, municipalities and (urban) districts. Secondly NDW is an executive responsible for managing and maintaining the traffic information database, contract management with suppliers and customers, stimulating of traffic data and development of new applications. NDW can also refer to the traffic (NDW, 2012; Seelen, 2012: Appendix D). NDW is currently busy to contribute to a high penetration and quality of traffic data for a national traffic database in the Netherlands. The organization of NDW requires the traffic data to be of a certain quality level before storage is allowed. Since the quality requirements seem to be too high to meet, joining NDW isn’t an option at the moment for the province and municipalities. If the requirements aren’t met, data suppliers receive fines: an extra threshold in connecting to NDW (Seelen, 2012: Appendix D, Appendix E, Appendix F).

The organizations mentioned are all directly involved to RTM, while contractors aren’t. Contractors are commercial parties indirectly involved in RTM by selling products and/or services. They for example deliver traffic light installations and maintenance contracts. Traffic measurements can be sold as a service as well (Seelen, 2012: Appendix E, Appendix G, Appendix H, Appendix I).

The amount of actors seems to be limited, but is rather complex. Especially because of the outsourcing of tasks such as maintenance and traffic measurements. To create a traffic overview on all three road levels, cooperation among the different kinds of road authorities is required. In order to guarantee data quality, it should also be clear who is responsible for what task within the information chain. Therefore interests should match functions, tasks and responsibilities of actors involved.

## 6. TECHNICAL

Now the complex field of actors and their responsibilities have been explored, this paragraph shows how the different actors are related to the technical part of RTM. The functional information chain of figure 1 serves as a guide through the technical systems.

The current technical situation is a result of the strong focus of road authorities on their own road network. Variety in the technical systems is also caused by European tendering rules. To be able to execute RTM, collaborations between the different road authorities and their systems are necessary (Rijkswaterstaat, 2011b, p. 35; Seelen, 2012: Appendix E, Appendix G, Appendix H).

*Measurements* are mostly done with inductive loops. The inductive loops of RWS are especially designed for measuring traffic. The idea is to measure traffic on provincial and local roads with the inductive loops of traffic light installations (TLI). Those inductive loops are designed to detect vehicles for the TLI. Counting vehicles is possible, but has some technical limitations. Compared to the RWS loops, these loops are often smaller to prevent false traffic detection. Another important limitation is the timeliness. Because of the cycles TLIs make, it is possible that an inductive loop doesn't count any vehicle within a minute. This can be caused by a red light. For that reason timeliness can't be shorter than a cycle period of the TLI. A difference can also be found in the penetration of inductive loops: on highways the penetration is remarkably higher compared to provincial and local roads (Seelen, 2012: Appendix E, Appendix F). The definition of data quality –accuracy, precision and trueness– is related to this technical part and should take different measurement methods and innovations into account. Innovations in measuring methods allows redundancy and the possibility to check the data quality, however using two measuring methods often costs more money (Seelen, 2012: Appendix F).

RWS realizes an average availability of their systems of 90%, while the agreement is to have an average availability of 97% (Seelen, 2012: Appendix D). A research of TNO in 2009 identified large accuracy problems in measurements: tens of per cent. It seems that inductive loops are susceptible to interference and active monitoring is only possible with an expensive parallel measuring system (Seelen, 2012: Appendix D, Appendix G, Appendix H).

*Data processing* starts at the measuring point. For RWS data is aggregated to data of 1 minute (Seelen, 2012: Appendix D). For the Province of Utrecht, the municipality of Utrecht and the municipality of Amersfoort data is aggregated to 5 minutes, because of the limitations of inductive loops that are part of TLIs (Seelen, 2012: Appendix E, Appendix G, Appendix H). Raw data is lost by aggregating data, so smaller time frames aren't only preferred because of timeliness but also for completeness. Data processing might become complex if more measurement methods are used for the same (part of the) road. This requires data fusion in data processing. To keep the 'raw data' safe, fusion of data should be done after storage (Seelen, 2012: Appendix F, Appendix I).

Technical *storage* details are left out in this research. The systems of NDW require about 65 seconds to internally process the data at NDW. That makes the total time from the road side measurement till the distribution 2 minutes. The hardware is organized in a way data is processed before storage. This makes it hard to determine the exact quality level of the (processed) data and raw data is lost during this process, as mentioned before.

By determining to store data based on (high) quality requirements, a lot of data is not stored. This means a lot of data is lost and can't be used for historical purposes as policy monitor and RTM evaluation. Better would be to store information about the data quality.

For *Transportation* of data RWS uses a parallel data stream for their own applications and for supplying NDW. The communication network of the Province of Utrecht is outsourced. The municipality of Utrecht uses wireless connections and suffers from availability problems. The communications infrastructure has consequences for getting the right data at the right time and place.

## **7. MANAGERIAL AND TECHNICAL INTERRELATION**

The previous two paragraphs explained the managerial and technical perspectives of guaranteeing data quality for RTM. The separate aspects are interrelated in two sub paragraphs. First the relation between managerial goals and technical infrastructure is explained. Thereafter influences of different applications are explained.

### **7.1. Managerial goals and technical infrastructure**

Accessibility and liveability are part of policy at a national, regional and local level (Ministry of Infrastructure and the Environment, 2011; Municipality of Amersfoort, 2005; Municipality of Utrecht, 2005; Province of Utrecht, 2008). Those policy goals of accessibility is for example done in vehicle loss hours and part of liveability is expressed in emission of CO<sub>2</sub> (Kennisinstituut voor Mobiliteitsbeleid, 2011; Ministry of Infrastructure and the Environment, 2011).

Basic input to calculate vehicle loss hours and CO<sub>2</sub> emissions are traffic measurements. Each of those goals might need different types of data. Whereas for vehicle loss hours travel times need to be measured, good estimation of CO<sub>2</sub> emissions might require measuring of vehicle categories. Those goals indirectly set requirements for the measuring instruments: they need to be able to measure travel times and vehicle categories. However of more importance is the quality of those measurements. If for example 30% of the vehicle categories aren't measured correctly, will the calculation about CO<sub>2</sub> emission be correct? Can it be said whether or not policy goals are met based on this calculation? It must be clear what level of data quality is required for policy goals. Therefore alignment between policy and technical infrastructure with data quality is necessary, making sure policy goals can be measured with the technical infrastructure.

### **7.2. Different applications, different quality requirements**

As mentioned the data quality requirements depend on the goal of the application that uses the data. The traffic data is for example used by two applications: regional traffic management and policy monitoring. Both of these require a certain level of data quality. Two information quality aspects selected for this example are timeliness and completeness. Comparing RTM and policy monitoring on the information quality aspect of timeliness, then timeliness is more important for RTM than for policy monitoring. If traffic data is too 'old' measures taken by RTM focus on the situation in the past based on the traffic data, while the current traffic situation might require other measures because of changes in the traffic situation. For policy monitoring the aspect timeliness is of less importance. This means that it doesn't matter if the data is available within 12 or 24 hours.

Regarding the aspect of completeness, for policy monitoring a complete overview is desirable. For example to determine the effects of RTM or to determine whether or not to extend road capacity. By taking RTM measures an indication of the traffic situation could be enough. Therefore policy monitoring require more completeness in comparison with RTM.

The organisation of using the data for different applications sets different quality requirements. Each quality requirement has consequences for the technical infrastructure. The timeliness requirement needs fast and reliable data connections for transport from measurement till the application. For completeness high availability of measuring systems is required with good storage facilities to be able to retrieve data later on.

In the ideal situation all applications and their specific data quality requirements need to be taken into account, since it is impossible to generalize the data quality requirements. In fact the use of traffic data for evaluation of policy, as explained in paragraph 7.1, can be seen as an application as well. A pragmatic overview will allow interrelating the managerial and technical perspectives. The solution for this problem is explained in the next paragraph.

## **8. ORGANIZATION PLAN**

The data quality requirements in information chains together with the organizational and technical explorations allow to draw up an organization plan to guarantee data quality in information chains for RTM. The organization

plan is based on the total data quality management (TDQM) of Wang (1998) (see figure 3). TDQM is based on total quality management (TQM) and compares the production of information products with physical products, retrieving the following four roles:

- “*Information suppliers* are those who create or collect data for the IP.
- *Information consumers* are those who use the IP in their work.
- *Information manufacturers* are those who design, develop, or maintain the data and systems infrastructure for the IP.
- *Information product (IP) managers* are those who are responsible for managing the entire IP production process throughout the IP life cycle”

The roles of information supplier, consumer and manufacturer have become clear in the managerial part of this article. One actor might have more than one role. The role of IP manager is missing in current practice and needs to be realized. The role is named *chain manager*. TDQM also identifies four steps towards guaranteeing data quality: define (1), measure (2), analyse (3) and improve (4).

The *define step* allows to clearly define data quality and make sure all actors involved share this definition. By setting the definitions the limitations of the technical systems and the applications that use the traffic data need to be taken into account. These applications determine what measurable quality indicators are necessary. In this step also responsibilities throughout the whole information chain need to be set and actors involved need interest for data quality be matched with their functions, tasks and responsibilities.

*Measuring* is required over the whole information chain and parts of the information chain. In that way the overall data quality can be determined and allows the *analyse step* to trace back the cause of bad data quality.

In the *analyse* step the chain manager will have an overview of bad data quality causes and can make an argued choice which parts of the information chains to *improve* in the last step. When this is done, the process will start again with the first step for continuous data quality improvement (Moody & Shanks, 2003).

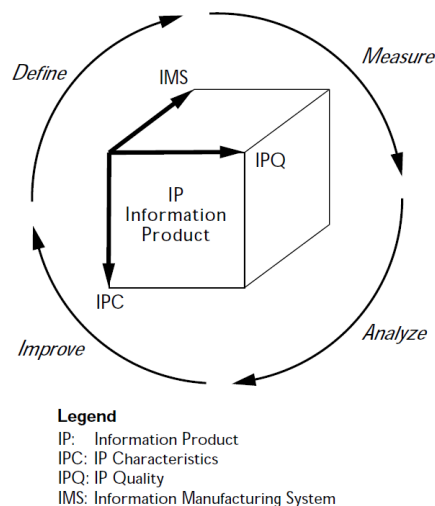


Figure 3 – TDQM methodology (Wang, 1998)

## 9. CONCLUSIONS

It can be concluded that a chain manager is necessary to integrate the managerial and technical worlds and guarantee data quality for information chains of RTM. This chain manager needs to take the four identified steps: define (1), measure (2), analyse (3) and improve (4). Strong cooperation between the directly involved road authorities, NDW and VERDER will be necessary to take those four steps. Since the lack of good and shared definitions, the chain manager first strongly needs to focus on this first step before moving on. Taking into



account the technical possibilities and limitations together with the managerial and political requirements will allow to set clear quality definitions as a prerequisite for the other data management steps.

## 9.1. Discussion

With the current knowledge the organization plan might seem to be an ‘obvious solution’. In fact it is a well-argued plan to organize information chains to guarantee data quality for RTM. Without specific knowledge about the RTM organization and specific technical infrastructure, creating such a plan would be impossible. The research exposes important problems related to guaranteeing data quality for RTM.

Interesting issue is the idea that it will be impossible to determine the (exact) effect of low data quality on the traffic system. Is guaranteeing data quality for RTM in that case useless? No. To be able to execute RTM a minimum level of data quality is necessary. Maybe the quality requirements are much lower than the requirements defined by NDW. A common say in Dutch is “meten is weten” and can be translated as measuring is knowing. Starting by measuring the current data quality, agreeing on adequate requirements can be a next step in RTM.

## REFERENCES

- Ackoff, R. L. (1989). From Data to Wisdom. *Journal Of Applied Systems Analysis*, 16(1), 3-9.
- Brinckerhoff, P. (2010). *Synthesis of Active Traffic Management Experiences in Europe and the United States*. New York: U.S. Department of Transportation Federal Highway Administration.
- Eurofiber. (2010). *Met de snelheid van het licht (With the speed of light)*. Amstelveen: JMG Publishing B.V.
- International Organization for Standardization. (1994). Accuracy (trueness and precision) of measurement methods and results, *Part 1: General principles and definitions*. Geneva.
- International Organization for Standardization. (2006). Statistics - Vocabulary and symbols, *Part 2: Applied statistics*. Geneva.
- Joint Committee for Guides in Metrology. (2012). *International vocabulary of metrology - Basic and general concepts and associated terms (VIM)*. Sèvres Cedex: Bureau International des Poids et Mesures.
- Juran, J. M. (1988). *Juran on planning for quality*. New York: Free Press.
- Kennisinstituut voor Mobiliteitsbeleid. (2011). *Mobiliteitsbalans 2011 (Mobility balance 2011)*. Den Haag: Ministry of Infrastructure and the Environment.
- Laudon, K. C. (1986). Data quality and due process in large interorganizational record systems. *Communications of the ACM*, 29(1), 4-11.
- Liepins, G. E., & Uppuluri, V. R. R. (1990). *Data Quality Control: Theory and Pragmatics*. New York: CRC Press.
- Ministry of Infrastructure and the Environment. (2011). *Ontwerp Structuurvisie Infrastructuur en Ruimte (Design Vision Infrastructure and Spatial Planning)*. Den Haag.
- Ministry of Transport, Public Works and Water Management. (2008). *Beleidskader Benutten - Eén van de pijlers voor een betere bereikbaarheid (Policy Framework Utilization - One of the pillars for better accessibility)*.
- Moody, D. L., & Shanks, G. G. (2003). Improving the quality of data models: empirical validation of a quality management framework. *Information Systems*, Vol. 28(no. 6), pp. 619-650.
- Municipality of Amersfoort. (2005). *VVP 2005 - De kaders voor het Verkeers- en Vervoerbeleid 2005-2015 van de gemeente Amersfoort (The framework for the Traffic and Transport Policy 2005-2015 of the Municipality of Utrecht)*. Amersfoort.
- Municipality of Utrecht. (2005). *Gemeentelijk verkeers- en vervoerplan Utrecht 2005-2020 (Municipal traffic and transportation plan Utrecht 2005 - 2020)*. Utrecht.
- NDW. (2008). *Eisen aan de Nationale Databank Wegverkeersgegevens (NDW) systeemketen (Requirements for the National Traffic Information Database (NTID) chain system)*. Nieuwegein.
- NDW. (2012). Organisatie - Over NDW (Organisation - About NDW). Retrieved 02-04-2012, 2012, from [http://www.ndw.nu/pagina/nl/3/over\\_ndw/27/organisatie/](http://www.ndw.nu/pagina/nl/3/over_ndw/27/organisatie/)
- Province of Utrecht. (2008). *Strategisch Mobiliteitsplan provincie Utrecht 2004 - 2020 (SMPU+) (Strategic Mobility Plan Province of Utrecht 2004 - 2020)*. Utrecht.
- Province of Utrecht. (2012). Verkeer en vervoer (Traffic and transport). Retrieved 15-01-2012, from <http://www.provincie-utrecht.nl/onderwerpen/verkeer-vervoer/>
- Rijkswaterstaat. (2008). *Betrouwbare verkeersgegevens binnen handbereik (Reliable traffic data within reach)*. Den Haag.

- Rijkswaterstaat. (2011a). About Rijkswaterstaat. Retrieved 27-06-2011, 2011, from <http://rws.nl/en/>
- Rijkswaterstaat. (2011b). *Jaarverslag Rijkswaterstaat 2010 (Annual Report Rijkswaterstaat 2010)* Den Haag.
- Rijkswaterstaat. (2012). Wegbeheer in Nederland (Road management in the Netherlands). Retrieved 02-04-2012, from [http://www.rijkswaterstaat.nl/wegen/feiten\\_en\\_cijfers/wegbeheer/](http://www.rijkswaterstaat.nl/wegen/feiten_en_cijfers/wegbeheer/)
- Seelen, P. A. G. (2012). *Organizing Information Chains to Guarantee Data Quality for Regional Traffic Management*. Delft.
- VERDER, & Arane. (2009). *DVM Sturingsvisie Midden Nederland (ATM Control Vision Middle Netherlands)*. Utrecht.
- Wang, R. Y. (1998). A product perspective on total data quality management. *Communications of the ACM*, 41(2), 58-65.
- Wang, R. Y., Kon, H. B., & Madnick, S. E. (1993). *Data Quality Requirements Analysis and Modeling*. Paper presented at the Proceedings of the Ninth International Conference on Data Engineering.