THE DUTCH MOTORWAY CONTROL SYSTEM
21 YEARS OF EVOLUTION

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The Dutch Motorway Control & Signalling System (MCSS originally, nowadays called Motorway Traffic Management system MTM)) was put in operation for the first time at the end of 1981 on a relatively small stretch of motorway (12 km) between The Hague and Rotterdam. Today this system covers 981 (from a total lengthe of about 2100 kilometers) including 8 tunnels. A total of five control centres are in operation. The paper describes the original system concept and how, from the practical experience with the system, this basic concept has gradually changed into the system it is today. Finally a brief overview of future plans is given.

Introduction

The Dutch Motorway Control & Signalling System (MCSS / MTM) was put in operation for the first time at the end of 1981 on a relatively small stretch of motorway (12 km) between The Hague and Rotterdam. This system was controlled from a control centre located near Delft. The idea was to learn enough from this pilot project to be able to install this system on many more kilometres of motorway.

The original system had two main functions:

1. A lane control facility offering tools to enable road works to be carried out more quickly and efficiently and also giving the possibility to take adequate measures in case of accidents.
2. An automatic incident-detection and -warning function, meant to obtain a reduction of the number of (secondary) accidents because of queues and other disruptions of the traffic flow.

A research facility was built into the system, in order to be able to measure the effect of the above mentioned functions, but also for the purpose of tuning the various parameters used.

After half a year of experimenting with the pilot system at Delft the system was considered to be stable, so the decision was taken to install it on a greater length of road. The "Delft" system was enlarged to about 40 kilometres; in 1982 the whole north part of the Rotterdam ring road was also covered. Also in 1982, a second motorway control system was installed on parts of the A2 and A12 motorways around Utrecht , covering about 60 kilometres of road and having its control centre near the city of Utrecht.

From 1982 to 1990 the growth in kilometres has not been very significant, only some small stretches have been added to these first two systems, like for instance a 7 km. stretch of road round the Schiphol tunnel on the A4 motorway.

An evaluation study, carried out in 1983 by the Delft Technical University, showed an overall reduction of the number of accidents of 24 %, an increase of traffic throughput during queues of 4.5 % and a smoother merging at temporary bottlenecks during road-works.

At the end of the eighties, it became clear that a system like this was really needed to cope with the increasing problems of congestion on the motorways, especially in the western part of the Netherlands. At the same time some other dynamic traffic management tools were developed (tidal flow, high occupancy lanes etc.) that needed a motorway control system as a basis.

As a result, a lot of building activities has taken place since 1990 and an ambitious construction program was carried out. The total length of signalised motorway sections increased from 200 to 985 kilometres (from a total motorway length of about 2100 kilometres, see Figure 1. Signalised sections of the motorway network). Four new control centres have been built:

1. near Velzen, covering the Amsterdam ring road and its connecting motorways
2. near Utrecht, covering the centrer of the country, and combined with the Traffic Information Centre and countrywide management activities
3. near Geldrop, covering the south of the country
4. near Arnhem, covering the east and north of the country

A fifth centre is being build near Rotterdam. It will cover the western part of the country and it will replace 3 other management centres now in operation near tunnels.

Figure 1. Signalised sections of the motorway network

During 1993 the central hardware, dating from the 1970's, was replaced by a small modern computer. We used this opportunity to translate all central software to a modern computer language (C), running on a modern operating system (Unix). The number of outstations one control system can handle was increased from 375 to 992, a necessity because of the rapid growth of the various systems.

In the following chapters, the original system concept will first be explained; after that this article will focus on how, from the practical experience with the system, this basic concept has gradually changed into the system it is today. Finally the plans for the nearby future will be briefly discussed.

One main concern of the developers and owners of these systems has always been the uniformity of the systems. After 21 years of use we have always been able to ensure that every control centre works exactly the same, and even that all roadside equipment in the whole country works exactly the same.

The basic system concept

When installing the first systems, the distance between gantries was alternately 500 and 1000 metres. This was based on the assumption that a lane reservation should start with a combination of a deflection arrow and a red cross on two gantries that were 500 meters apart. In practice this pattern could not always be followed; especially near intersections where the matrix signals are mounted on existing route indicator gantries which are at much closer distances. Detector stations were originally placed at 500 meter intervals; 200 meters behind a gantry and - where gantries were 1000 meters apart - also at 700 meter from a gantry. Most matrix signs were mounted on gantries, although a limited number of post mounted signs were used as well. The original lay-out is shown in Figure 2. Initial and current lay-out.

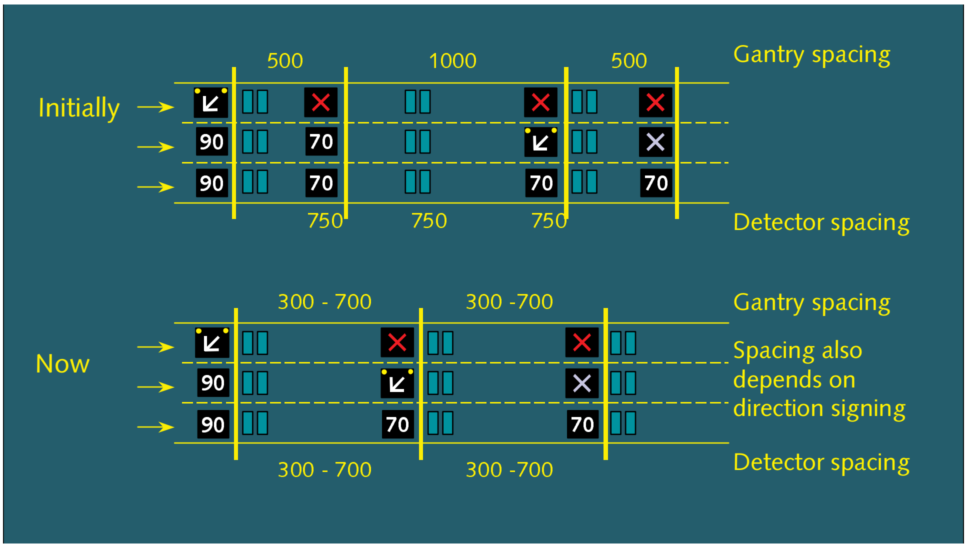

Figure 2. Initial and current lay-out

The signs used in the matrix signals were originally 30, 50, 60, 70, 80 and 90 km/h, a red cross, deflection arrows (left and right) and an end-of-limits sign.

After some years of practical experience, the ideas on gantry- and detector-spacing changed dramatically. We found out that gantries should be spaced as evenly as possible, and that the ideal distance between gantries was 700 to 800 meters. Again, near carriageway-splits and intersections distances are sometimes 300 to 400 meters because of the combination with directional signing. Experience with the AID-mechanism learned that detectors should be placed directly behind a gantry. The mean distance between detector stations went from 500 meters to 350 to 400 meters because of gantry distances.

Post-mounted signs turned out to have such limited possibilities that nowadays they are hardly used any more.

Graceful degradation and safety

When building the MTM we carefully designed a graceful degradation concept. This means in practice that the system will work on in a safe way, even if parts of the system fail. During the 20 years of operation no significant changes have taken place regarding this concept.

If the contact with an outstation is lost (because of a breakdown of the central computer or because of a communications failure) the outstation will switch to "local mode". In local mode, it will retain the last signs commanded by the central computer and also run its own local AID program. This can even result in more restrictive signs, if a queue situation should necessitate that.

Every outstation is connected to two or three detector-stations, in such a way that the last detector-station is the first one of the downstream outstation. By providing this "overlap" we can ensure that local AID-signs resemble as much as possible the effect of central AID and - if an outstation should fail - the upstream outstation will still have all relevant detector-data.

In the event of a power failure at an outstation, a battery is used to continue the display of the matrix signs (originally only crosses and arrows, today all signs). A second battery is used to preserve the information in the RAM-memory.

All lamps of all signs are continuously monitored (also when they are not used), as well as all detectors in the system; every error is immediately reported to the system operator. The red cross is formed by 3 lamps (each of them forming a complete cross), so a failing lamp will not contort the picture. A failing deflection arrow will immediately be replaced by a cross.

Two central computers are used, the second one on cold stand-by. If the operational computer fails the other one can be operational after a number of minutes, using the same set of data.

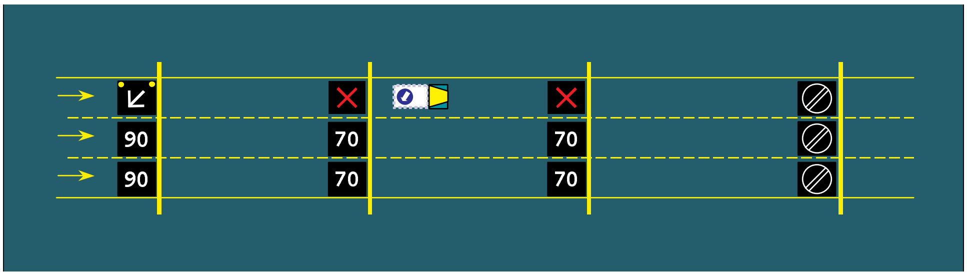

Figure 3. Principle of lane closure with Action vehicle

The traffic management functions

The lane control facility has undergone a number of changes during the years. The most important changes were:

1. Since the 1000-meter gantry spacing distances have been abandoned, lane closures can start on every gantry now.
2. The use of flashers has been reduced to the matrix with the deflection arrow only; initially flashers were used on every matrix of the gantry at which a deflection arrow was shown, as well as round the first 70 signs. The current lane closure pattern is as depicted in figure 2.
3. When two or more lanes have to be closed, this is done in stages. The time between 2 stages has been reduced from 2 minutes to 40 seconds.

Figure 4. Lane closure at night

4. The first real blockage on the road (usually a trailer with a big flashing arrow) was originally positioned at about 300 meters behind the first. After some experience this distance was reduced to about 50 meters. The principles of a lane closure as excuted during road works can be seen in Figure 3. Principle of lane closure with Action vehicle. An example of a lane closure is pictured in the photo of Figure 4. Lane closure at night.

5. The system contains a mechanism to predict when queues will form in case of an anticipated closure of a number of lanes. It uses historical flow data in order to make this prediction. This mechanism proved very successful and is used quite often when maintenance work is being planned.

The Automatic Incident Detection (AID) mechanism has undergone a lot of changes as well. Again, the most important ones are worth mentioning:

1. Initially two facilities were provided: Open Loop AID (OLA), where the system proposed a speed warning and asked permission from the operator, and Closed Loop AID (CLA). During the pilot phase (the first half year of operation) we needed OLA for some time while the system still had to be tuned. Soon afterwards, CLA proved such a success that the OLA possibility was removed. Anyway, in bigger systems the operator could never have held pace with the number of proposed changes.

2. Initially, a queue-warning consisted of successive speed-indications of 70, 50 and 30 km/h, while an end-of-limits symbol was used to indicate the "free again" situation. The 30 km/h proved too severe, whilst the end-of-limits was often immediately followed by speed indications again in case of speed disruptions over longer stretches of road. Both the 30 and the end-of-limits are no longer used for AID, so queue-warning now only uses a 70-50 sequence to warn oncoming traffic for a standing or slow moving queue.

3. Initially the AID-mechanism used a 20-second interval between the changing of AID signs. At the moment AID signs can change every 4 seconds if the traffic situation makes this necessary.

4. For the detection of incident situations the original mechanism made use of three different parameters. The first was based on the mean speed, the second on the mean flow

and the third mechanism took lane changes between two adjacent detector-station into account. After a lot of practice, and many off-line studies as well, we decided to use only the mean speed as a basis for AID.

Operation of the system

In this area the biggest changes have taken place. The original set-up consisted of separate monochrome graphical user interfaces (GUI's) for 6 operators (1 system-operator, 3 traffic operators, a police-operator and a GUI for training). On each of these GUI's measures could be taken, and the system combined these measures. In practice the main traffic operator (in Holland an employee of the Ministry of Transport) soon used two or more of these GUI's at the same time. Since 1990 the user-interface has changed considerably.

Figure 5. The control room near Utrecht

Every operator (8 operators can work on the system simultaneously now) uses a workstation with two 19 inch LCD colour-screens now. On the first screen a graphic overview of the whole system can be shown, while the second screen is used for the measure set-up process and the presentation of information and alarms. One operator can work on more than one measure simultaneously, if necessary. Figure 5. The control room near Utrecht shows a modern control room for both motorway and tunnel control.

Addition of new functions

After the system had been used for a number of years, the wish for some new functions arose. In many cases our policy has been, and is, to try a proposed new function in one of our control centres without immediately changing the central software of the system. The traffic smoothing algorithm for instance was tested by building an extension to the software of the workstation that handles the user-interface. A change will only be included in the central software of all control centres if the outcome of the evaluation is favourable.

An overview of such new functions:

1. Combination with tunnel systems
   In 1990 we had to install the Motorway Control System on the Amsterdam ring-road. This motorway crosses the river IJ via a tunnel.
   Since in motorway-tunnels like these a lot of equipment is used that influences traffic as well, it became necessary to combine the tunnel system and the motorway system. The operator-interface was changed in such a way that all equipment influencing the traffic is dynamically shown on one screen. Since contra-flow via one of the tunnel-tubes is sometimes used, special safe-guards against conflicting traffic measures were built in as well.
   At the moment all 7 river-crossing tunnels are incorporated in the MTM-system, all in the same way.

2. Tidal flow lanes
   On the A1 motorway (Amsterdam-Amersfoort) a so-called tidal-flow- or changeable lane, located in the central reservation, is in operation. In the morning rush hour this lane is used in the direction of Amsterdam (originally for cars with 3 or more occupants only, but that has been cancelled after public opposition) and in the evening rush hour in the opposite direction (for all traffic). Some changes to the MTM were necessary to make such use possible.

3. Fog-detection and –warning
   In 1991 a fog-detection and -warning system was placed on the A16 motorway (Rotterdam-Antwerp) near the city of Breda. During the first year, this system was a stand-alone application, but at the end of 1992 we installed MTM on this road and had to combine both systems.

4. Local actions
   Since motorways in Holland have bridges and tunnels in them it is sometimes necessary to stop all traffic. For instance after detection of a vehicle which is too high to enter a tunnel, or when a bridge is going to be opened. In such cases the motorway control system is used to gradually stop the traffic by showing a decreasing sequence of speed indications (90-70-50 or 70-50). But as in such situations actions have to be taken very quickly and reliably, we have chosen to perform the action locally and to inform the control centre only afterwards. The signs resulting from these local actions are combined (per gantry) with signs that are already shown. The same goes for the removal of these local measures.

5. Traffic smoothing
   In 1992 a traffic smoothing (Dutch: Homogeniseren) experiment was carried out on the A2 motorway (Utrecht-Amsterdam).
   The idea was to keep traffic moving as long as possible by showing speed indications over relatively long stretches of road during periods of high traffic flow. The speeds used were 90 or 70 km/hr, and the main philosophy was based on the supposition that if speed differences were less, the possibility of queue-forming was less as well. The evaluation were somewhat disappointing. For this reason it took 10 years for an other experiment to start n 2002.

6. Use of the hard shoulder
   The motorway control system has been changed in such a way that it is possible to use the hard shoulder on certain roads during a part of the day. Since three years this measure is in operation. Due to the discussions on safety issues, this measure is always combined with video-camera's covering the whole section and strict procedures during startup and closing down of the so called "rush hour lanes".

7. Monitoring information
   A small change of the system-software has made it possible to "export" traffic data like

speed and flow to the so-called monitoring system.
The monitoring system is a central system which collects traffic data (both dynamic and static) from all over the country. Thus this monitoring-system does not need separate data-collection points on motorways where a motorway control system is already present. For research purposes a similar facility has been built in, which makes it possible to export some data (like signs shown, speed, flow) from the system for research purposes. The difference with the "real" research facility is that this export facility only provides aggregated speeds and flows, while the research system can give all the information on a vehicle level.

Current developments

With the new hard- and software as a basis another update of the system is underway. Together with the regional directorates of Rijkswaterstaat an list of the wishes for such an updated system was made.

The most important changes will be:

1. The maximum number of lanes will increase from 4 to 8;
2. Local AID will not only override central AID, but even take away central AID signs if necessary;
3. A complete renewal of all rules and tests used for the calculation of traffic measures;
4. An operator will be able to "prepare" traffic measures, test them in advance and thus place them more quickly when necessary;
5. A better facility for the temporary use of the hard shoulder;
6. A better mechanism for the coordination between adjoining control systems, and
7. A complete new user-interface, now totally in a graphical form.

Future developments

In The Netherlands the Testcentre for Dynamic Traffic Management systems of Rijkswaterstaat is stimulating the progress of innovative telematic projects. The final objective is an integrated traffic research laboratory to proceed and to accelerate the 'state-of-the-art' in DTM in practice. Expected advantages of such a laboratory are:

1. training in the behavior of the system and how to deal with exceptions;
2. reduce the risk and cost associated with deployment;
3. facilitate the evaluation of technologies and allow for technology transfer;
4. develop, test, and evaluate new concepts and technologies
5. quantify the operational benefits, safety, and environmental impact

To facilitate their development a proper architecture must have been decided between partners involved. Particular attention should be paid to the interfaces between the components as well as the data definitions. In Figure 6. The components in a Traffic Research Laboratory all possible components in a traffic and transportation research laboratory are depicted. It is important that the 'ex-ante' models map well upon the different parts in the control centre. Mark also that the decision support parts will contain models for their own prediction purposes.

1. **Reference Control Centre**
   is a copy of the technical components in an operational regional trafficmanagement-

and control centre. It is important to recognize that some layered structure should exist and that a decision support system is part of such a control centre.

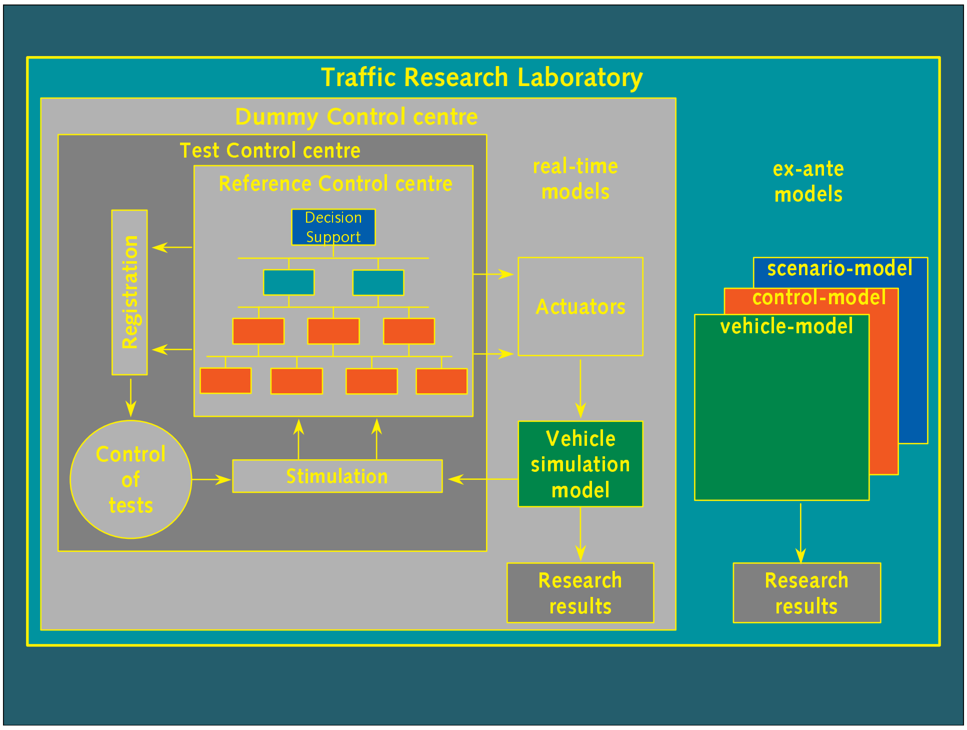

Figure 6. The components in a Traffic Research Laboratory

2. **Test Control centre**
   is an add-on of the Reference Control centre. It is meant for testing existing and new developments against the functional and technical specifications in a so called Site Acceptance Test (SAT). In order to do so, a stimulation unit under control of a testunit activates the appropriate inputs of the device(s) under test. A registration unit records the reactions of the system and, in case of any malfunctions, allows for reasoning about the reasons and solutions.

3. **Dummy Control centre**
   is an add-on of the Test Control centre. A vehicle model simulates the reaction of the modeled road-users on the actuators. These reactions are fed into the stimulation unit. Other elements in the model are the road network, route choice behavior, etc. It is possible to do research on existing situation and to train candidate operators in an realistic behaving environment.

4. **Traffic Research Laboratory**
   is an add-on of the Dummy Control centre. In a neat architecture important parts of the models can be exchanged, for instance the 'ex-ante' vehicle models with the real-time vehicle models or the decision support unit with the scenario model or the control models with the equipment in the reference part. But this is still far from realization.

The development of a Reference-, Test- and Dummy Control centre into a Traffic Research Laboratory is a complex and evolutionary process. Some similar developments have been recognized in different area's like air traffic guidance.