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ARE SAFER ROADS BETTER ROADS? THE INFLUENCE OF SAFE ROAD DESIGN ON THE PAVING PROCESS AND THE QUALITY OF THE PAVEMENT

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ABSTRACT

Over the last decades road design has become more complicated. The push for more safe design has had a major impact and sparked an extensive growth of special road constructions, like roundabouts, refuges, different asphalt colors, speed bumps, etc. This rapid growth in variety is a result of the new design methodology 'Safe system approach', in the Netherlands called 'Sustainable Safety Vision'. Although proven to be more safe, and therefore widely accepted, these new safe road solutions create cost and quality concerns for the industry. The complexity and variety lead to disturbances in the paving process and generate an increasing amount of handwork. The problem is that there is no standard procedure to spread and (pre)compact the asphalt by hand. Initial temporarily results show a higher variability in densities and maybe even a structural lower density around these special road constructions.

This paper documents some of the consequences of the new design methodology in terms of the amount of handwork, the density and the variability in the density. The data are gathered through observation during a project and subsequently drilling cores at specific locations. These cores were analyzed in laboratory to determine the mechanical properties. This study also provides some first understanding about the complexity of handwork and will make suggestions for future research. Given the outcomes of this first study, the paper argues [a] for more research towards a more clear and standard procedure for handwork, ***education of road designers on constructability issues in relation to safe design.***

Keywords: Density, Handwork, Quality assurance, Safe system approach and Standardisation

1. INTRODUCTION

In the last decades a lot of extra functionalities are required from the Dutch asphalt pavements. Beside structural and mechanical properties, such as load-bearing capacity, resistance against cracking and rutting, also functional properties become more important. Examples of functional properties are water drainage, noise reduction and improved skid resistance. Huerne & Doree (2006) postulated that the paving process is vulnerable to changes and with that quality issues can arise.

Not only the properties of the asphalt mix and the paving process are subject to changes. Also road design rules changed over the last decades. The road design rules mentioned in this paper concern rules about geometry and spatial design (curves, lane width, intersection layout, etc) and thus not mix or layer configuration design. These design rules seem to directly influence the paving process. The changes in road design in the Netherlands come for a substantial part from a safety perspective and in particular from the 'Sustainable Safety Vision'.

This paper will focus on the consequences of new road design rules on the asphalt paving process. It first discusses the practical implications of the 'sustainable safety vision' (Dutch: 'Duurzaam Veilig') on road design. Next a review is given how the new road design influences the asphalt paving process. The paving process is substantially depending on the experience of the asphalt team. It is likely that current working procedures in the paving process are no longer valid or at least need improvement to maintain the desired quality of the HMA pavement. A case study is conducted to get some first insides of the quality parameters of an asphalt pavement in different situations. The different situations vary from 'strait forward' paving to paving of special constructions resulting from specific (new) road design rules. From the results of the case study (preliminary) conclusions will be drawn about quality parameters and paving process procedures. Finally the need and direction for future research is discussed.

2. A SAFE(R) ROAD DESIGN

Before focusing on asphalt paving process this paper will give some backgrounds on the 'Sustainable safety vision' (SSV). It is important to see how strong it influences the current road design. The SSV was initiated in de last decade of the 20th century. The program was initiated because of the high and rising number of traffic casualties. In the mid '80 there were far more than 1000 casualties due to traffic accidents in the Netherlands (Wegman & Aarts, 2006). The SSV consisted of a number of measures with clear and ambitious goals about the number of casualties and injured due to traffic accidents in the future. In 2009 the number of traffic casualties dropped to around 700. It is difficult to quantify the exact effects of the SSV but research show strong suggestions that the SSV had a strong effect on the improved road safety (Weijermars & van Schagen, 2009).

The measures in the SSV included a better education of the road users, enforcement and a safer road design. The safer road design in the SSV is based on five principles (Stichting Wetenschappelijk Onderzoek Verkeersveiligheid [SWOV], 2010):
1. (Mono) functionality of roads
2. Homogeneity of mass and/or speed and direction.
3. Predictability of road course and road user behaviour by a recognizable road design
4. Forgivingness of the environment and of road users
5. State awareness by the road user

The first four principles have a direct effect on road design and in the end possibly on the paving process. These principles will be explained a little further:

Traffic has two, both very different, functions: to flow and to exchange. Roads with either a flow or exchange function are considered safer than a road which facilitates both functions (SWOV, 2010). The second principle focuses on the situation when road users (or vehicles) with large differences in mass use the same road. Then the speed should be low, so vulnerable road users come out of a crash without severe injuries. If it is desirable that the speed is higher, the different types of road users and road users driving in different directions should be physically separated from each other as much as possible (SWOV, 2010). These two measures lead to road constructions like lane separation, special intersection layout to avoid frontal conflicts and special purpose lanes.
The predictability of roads is imposed to prevent unsafe actions in traffic as much as possible because road users know what to expect and what will be expected of them. People make fewer mistakes when they have to react to traffic situations they expect than when they have to react to an unexpected situation (Theeuwes & Hagenzieker, 1993). Therefore is important to make uniform road designs. Occasional and extraordinary designs to improve the paving process are therefore difficult to implement.
The fourth principle is based on the idea that traffic is a social system in which crash causes can (partially) be traced to the interaction between road users. For the road users it is important to allow for each other's shortcomings.

In important Dutch road design manuals as the 'ASVV' (design manual for road in urban areas) and 'Handbook Road Design' (Dutch: 'Handboek wegontwerp") (design manual for roads outside urban areas) the principles from the SSV are implemented (and Wegman & Aarts, 2006). The design manuals also take in account issues concerning environment, traffic flow and comfort of roads to road users. On the other hand, practical implications of the design on the paving process, is not considered.

Although the design manuals are not considered as 'law' they are often followed strictly. The manuals are even used more and more in (civil) court in cases concerning traffic safety issues. There are a number of known cases where a victim of a traffic accident successfully sued the government because the road design was not designed according to these design manuals and therefore unsafe.

3. CONSEQUENCES OF A SAFER ROAD DESIGN

Roundabouts
A roundabout is considered as one of the safest solutions for an intersection. At an intersection road users with a different mass and speed meet each other. According to the Homogeneity principle the speed should be reduced. At a well designed roundabout the speed reduction is enforced by the layout of the roundabout (maximum speed at the intersection 35 km/h). Furthermore there is a reduced number of possible conflicts with other traffic and frontal collisions are prevented (CROW, 2002). The 'Handbook road design' (CROW, 2002) states that a roundabout is the preferred solution for in intersection on distributor roads. Wegman and Aarts (2006) even state that a roundabout is a SSV requirement. According to the Dutch National Roads Database (NWB) in 1998 there were 1477 roundabouts in the Netherlands. In 2007 this number was increased by 2366 to 3843.
The impact of roundabouts on the asphalt paving process seems evident. Especially on smaller roundabouts it is not possible to pave in 'one go'. The narrow radius causes problems with asphalt mix spreading. 'Gaps' in the spread pavement have to be filled by hand. Furthermore the connecting roads often have curves and refuges. This is also likely to cause more handwork (see below). A quick review among asphalt paving contractors shows that there is no real consistency in working method when it comes to paving roundabouts.

Refuges and lane separation
These constructions make sure road users with a different speed and direction are physically separated from each other. Furthermore, refuges provide road users a safe haven if an intended lane crossing is not possible after all. The road user can then stay on the relatively safe refuge instead of the middle of the road.
For the asphalt paving process refuges and lane separation pose a problem. The edges of the refuges are seldom strait. The width of the (connecting) pavement between the lane separation and refuges is often too narrow for the paver (see figure 1 and 2). Therefore handwork is needed. Also the paving has to be conducted in different phases and (longitudinal) joints will likely occur. In the compaction phase not all rollers can reach the whole surface. Therefore alternative roller use and patterns are needed.

Figure 1 and 2: Manual asphalt spreading is needed at a refuge.

Different asphalt colors
To separate different road users and give them their own place on the road different colors of asphalt are used. In the Netherlands it is common to give bicycle paths a red top layer. A different color of asphalt can also be used on junction's planes to raise awareness of the road users.
If different colored asphalt mixes are used it also means that, at least the top layer, has to be paved in different sections. It is very likely the paver has to stop more and more (longitudinal) joints occur.

Speed reducing constructions (speed bumps and chicanes)
At roads where all road users use the same space the SSV states that the speed should be low and enforced. Therefore speed reduction measures should be applied. These measures include speed bumps, chicanes, etc. All these speed reducing measures pose as a disturbance in the HMA paving process. The paver cannot pave in a straight lane and/or small surfaces have to be paved.
From the above examples one can conclude that the following issues increase if these constructions are applied:

- Disturbance of the paving process (e.g. stopping places paver)
- Spreading asphalt by hand (e.g. shovel or dragline)
- Alternative working (paving and rolling) procedures
- More (longitudinal) joints because of different colors/types of asphalt and the asphalt is paved in different phases

Brock and Jacob (1999) state that the two most common problems in premature failure of hot mix asphalt roads is failure at longitudinal joints and segregation. Segregation problems are more likely to appear when asphalt is not spread with an asphalt paver but with a shovel or dragline. Brock, May and Renegar (2003) suggest that segregation is potential treat in every part of the paving process form production to placement. Every time asphalt is transported, therefore also from the truck onto the pavement, without the right procedure segregation problems can arise. It is thus clear that the 'special' road constructions mentioned earlier in this paragraph are more likely to be vulnerable to these problems.

Figure 3 and 4: Longitudinal joints between different colored asphalt. First failure is visible (left). Segregation is clearly visible at a refuge (right).

The Asphalt-Institute (2007) states that the two of the most important factors affecting asphalt layer quality are the temperature during the paving and the final density after paving and compaction. The compaction of the HMA should take place in a certain time frame. If the temperature in the HMA is too high the material lacks stability to support the weight of the roller. When the temperature in the HMA is too low the roller does not create shear forces sufficient to increase density. In either case it is difficult to achieve optimum density and mixture performance problems might develop (Miller, 2010). Miller also shows that there can be large variations in the temperature of the asphalt mix when paved. Stopping of the asphalt paver seems to contribute to the temperature variations. At the 'special' road constructions the paver is more likely to stop and variations in temperature are therefore also more likely. The manual spreading (shovel or dragline) doesn't seem to have a positive effect on a constant temperature as well.

This suggests that at these special road constructions there might be quality issues regarding the asphalt pavement. While at these special road constructions the quality maybe even more important than at regular, 'strait forward' pavements. At and near roundabouts, refuges and speed bumps traffic is likely to slow down, turn and/or accelerate. These actions put extra strains and stresses on the pavement.

4. CASE STUDY

A lot of research about quality and factors contributing to quality is conducted in cases where de asphalt pavement consisted of a 'strait forward' pavement with a constant width. In these cases the paving is also done with an asphalt paver and no manual spreading. There are hardly any (systematic) results about the quality and factors contributing to the quality in case of handwork.

The results presented in this paragraph are from an actual asphalt paving project done in 2010. The project consisted of an urban road with two separate lanes. In the project only one of lanes was paved. The road had some wide curves and a couple of intersections. At the intersections also the connecting part between the two lanes had to be paved. The project was divided in three sections of about couple of 100 meters each.

The project was part of a PQi as described by Miller (2010). Most of the project was quite strait forward. The paver could lay the asphalt in large stretches with a constant width. At some intersections and (bicycle) crossings the paver could not be used and therefore the asphalt had to be spread manually. Also in one of the curves a small strip of asphalt had to be spread manually. Compaction was done with two rollers. First a three drum roller and then a non vibrating tandem roller.

Variations in density

To determine final density of the asphalt mix throughout the project, test cores were cut from the asphalt and tested in a laboratory. At most locations where cores were cut, the nuclear density was also determined to get a first indication of the density onsite. However the nuclear density is not used further for this research because the laboratory tests are considered more accurate. The systematic differences between these two values are most likely caused by the different methods of measurement (Paldo, Mahoney, Aultman-Hall & Zinke, 2005). Throughout the whole project 47 test cores were cut in 15 different situations. The situations varied from a straightforward paving process with a constant paving speed (at these places also thermocouples where placed) to manually spreading asphalt at a special road construction.

There is too few data to do a full statistical analysis. The analysis is done to give a global indication of quality issues concerning handwork.

Section 1:

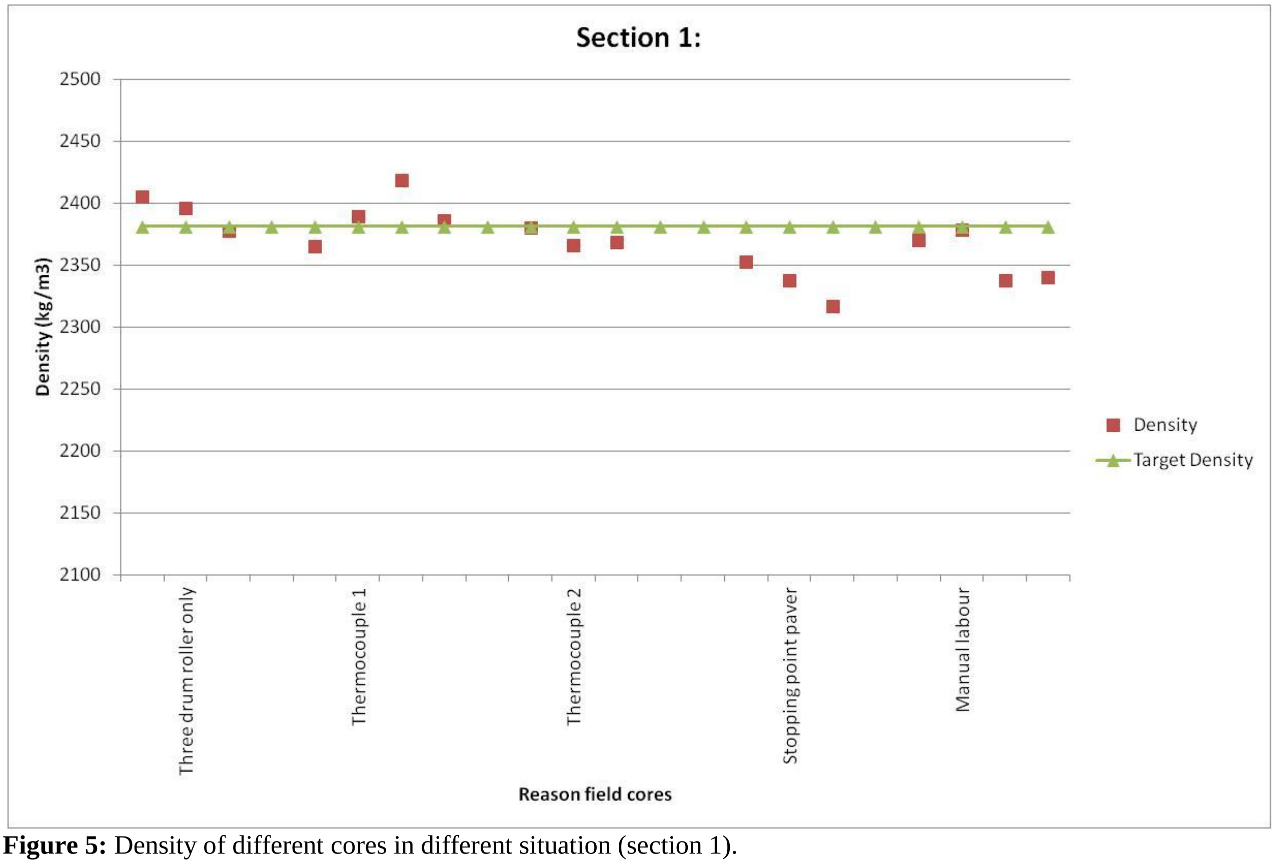

Figure 5: Density of different cores in different situation (section 1).

In section 1 17 test cores were cut at different places. The thirst three cores are from a zone where the asphalt was only compacted with a three drum roller and not the tandem roller. The next 7 cores were taken from two spots where thermocouples were placed ('strait forward' paving). In these spots there were no problems with the final density. The achieved density is around the target density. Next 3 cores are taken at a spot where the paver halted for a longer period of time. The target density is not reached there. The last 4 cores are taken from a part where the asphalt was spread manually. The density is not far from the target density but they are all lower than the target density under it.

Section 2:

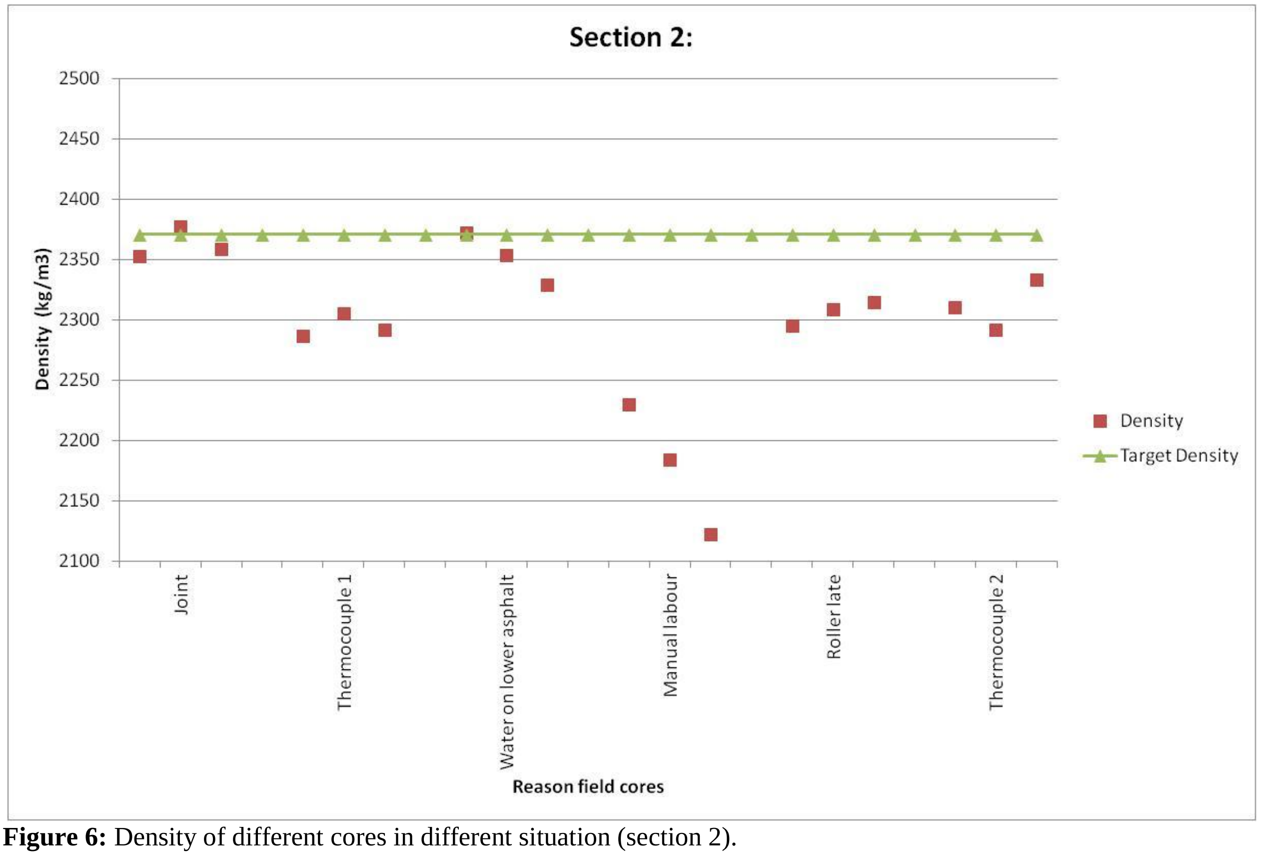

Figure 6: Density of different cores in different situation (section 2).

In this section there seems to be an overall problem with making the target density. Small disruptions like a roller being late don't seem to have a big influence. At the location of the thermocouples (again: 'strait forward' paving) the target density isn't met. It is very clear that the zone where the asphalt spread manually not only the target density isn't met at all but also the variation in density is quite high.

Section 3:

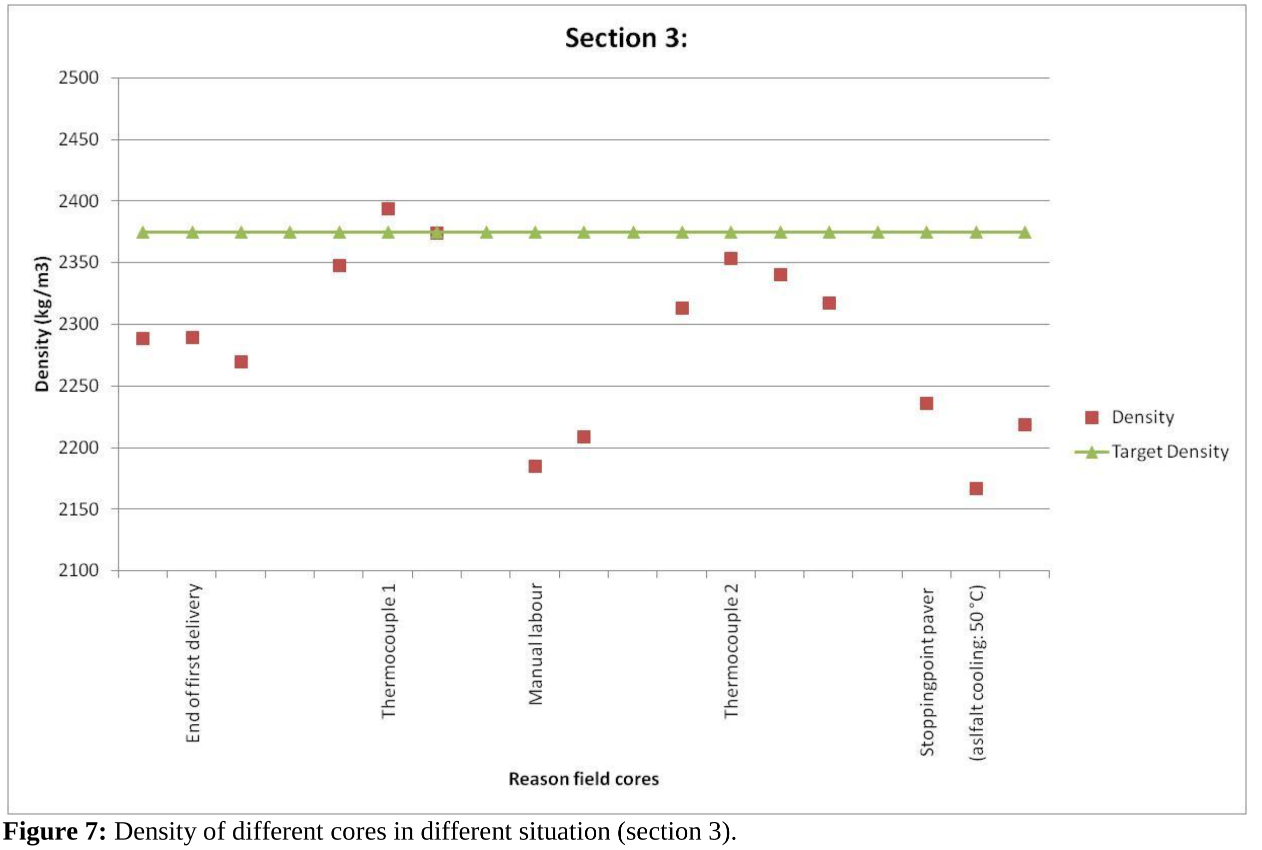

Figure 7: Density of different cores in different situation (section 3).

In section 3 the same ‘problems’ concerning density occur. The cores taken near the thermocouples show a reasonable compaction. At places where the paver halted for a long time and where manual asphalt spreading was needed the target density wasn’t met.

5. IMPLICATIONS FIRST RESULTS FOR THE INDUSTRY

Although the results come from one single project, they do give an indication about the final density of asphalt pavements near handwork. The results show that the final density of the asphalt pavement at places where handwork is applied is lower and variations are larger. There are several possible explanations (Brock, 1999; Asphalt-Institute, 2007; Miller, 2010):

1. The initial temperature of the asphalt was too low (or too high).
2. Segregation of the asphalt mix because of the manual spreading
3. Incorrect rolling procedure

It is not possible to give an exact and definitive explanation why the target density isn’t reached in these situations. The project in the case study was part of a PQi but at places where handwork was needed the paver speed and temperature of the paved asphalt wasn’t measured. Some visual observations were made to identify segregation. At certain places where the asphalt mix was spread manually it was very clear the surface showed signs of segregation (e.g. see figure 4). However this was not investigated systematically. Therefore it is not possible to draw any conclusions about the degree the initial temperature and segregation contributed to the lower density.

The number of roller passes could be determined by using the GPS data of the rollers. With this data roller procedures/patterns might be determined. However at this moment, with the current data analysis methods, it is very difficult to extract the right data from the raw GPS data. Besides, the asphalt temperature when the rolling took place is also important (Miller, 2010), but this temperature is not available because the initial temperature wasn’t measured. Therefore it is also difficult to draw any conclusions about roller procedures.

The cases study only focused on final density of the asphalt pavement in different paving situations. But also functional properties like water drainage, noise reduction, flatness and skid resistance might be affected by handwork.

6. CONCLUSIONS AND FUTURE RESEARCH

The SSV approach is successful from a safety perspective (Weijermars & van Schagen, 2009). However, this approach implies that special road constructions, like roundabouts, refuges, speed bumps, etc need to be applied. These special road constructions are, in their turn, very likely lead to discontinuities in the asphalt paving process. The first results of a case study at an actual construction site show that the quality of the asphalt pavement is vulnerable for these discontinuities.

Because of the supposed success of the SSV it is very likely that in the future the special road constructions resulting from the SVV will stay. Possibly in newer versions of the road design manuals, the paving process can be taken into account together with safety related and other aspects. For that, research is required about how road designs influence the paving process and how this can be optimized.

Although road design rules can be optimized for the paving process it is still likely that handwork will remain in some cases. The case study suggests there are additional quality issues in case of handwork. Further research is necessary needed to investigate which factors and to what extent these factors contribute to (the lack of) quality in cases of handwork. For that the current PQi as proposed by Miller (2010) should be adapted and expanded further. When it is clear which factor(s) contribute to quality of handwork and to which extent, paving and rolling procedures can be adapted accordingly.

We would like to develop a relevant and valid research agenda for future research on these subjects. We invite everyone to participate in a discussion about research goals and direction.

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