CEDR Transnational Road Research Programme
Call 2013: Energy Efficiency – Materials and Technology

Funded by Germany, Norway,
United Kingdom, Netherlands,
Austria and Slovenia

CONSISTEND: A tool to assess the impact of construction process quality on the performance of pavements and its implementation in tenders

WP4- Report 4a: Report on the demonstration projects

The Netherlands Organisation for Applied Scientific Research (TNO)
Roughan & O' Donovan Innovative Solutions (ROD-IS), Ireland
TRL (Transport Research Laboratory), UK
The Slovenian National Building and Civil Engineering Institute (ZAG)

CEDR Call 2013: Energy Efficiency
CONSISTEND
A tool to assess the impact of construction process quality on the performance of pavements and its implementation in tenders

WP4 – Report 4.1a: Report on the demonstration projects

Due date: 28/02/2016

Start date of project: 01/05/2014 End date of project: 01/05/2016

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Version: FINAL June 2016

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Executive summary

The service life of pavement surface courses is highly dependent on the construction process. A large number of parameters have to be controlled and kept at optimum during the transport, laying and compaction process. The temperature of the asphalt mixture during laying and compaction process (roller passes) has the most critical effect on the uniformity of the degree of compaction and the evenness of the asphalt layer. Segregation and cooling of the asphalt mixture during transportation reduces the life span of a pavement.

New innovative quality control techniques for transport, laying and compaction (TLC) process have been developed. Contractors and road managers understand the benefits of these techniques, however it is not yet possible to objectively weigh the costs of these techniques against the value. In WP2 a tool was developed to assess the impact of the quality of the construction process on the performance of pavement. The tool evaluates the TLC process during which numerous actions may trigger weaknesses and thus shorten the lifespan of the asphalt. In the CONSISTEND model the results of the tool are based on purely empirical 'expert opinion' regarding the influence of TLC on pavement lifespan.

To demonstrate the applicability of the proposed tool two pilot studies were organised. The results showed that the application of advanced quality control techniques during construction can provide a much more detailed and more reliable insight into the quality of the actual transport, laying and compaction process, and thus into its influence on the pavement lifespan prediction.

The 'real case' project in Slovenia completed in 2015 identified in detail the benefits of innovative techniques for control of pavement works. The testing of devices for Infrared (IR) scanning of thermal profile also allowed for measuring and recording of weather conditions and paver speed. However, it was established that this quality control technique cannot provide measured results for all of the input parameters of the tool.

In order to demonstrate the applicability of the proposed tool, the lifespan prediction for the 'during contract phase' with that for the 'after construction phase 1' was compared taking into account the results of the usual scope of quality control and that for the 'after construction phase 2' taking into account the results obtained by the devices for automated monitoring of paving process. Results of lifespan prediction with the tool demonstrate that the mean value of the predicted lifespan lies between the minimum and maximum lifespan, as expected. However, the change in mean value of the lifespan prediction is relatively small, and smaller than expected by the experts in the CONSISTEND project team.

To increase the response of the model to a change in values of the input parameters, significantly less input parameters should be defined in a next version of the tool. It was proposed to introduce weighting factors to individual input parameters. For some construction parameters, research results have already defined some inter-dependencies. However, clear and straightforward inter-dependencies of the parameters, measureable with advanced quality control methods, on the absolute increase or reduction of pavement lifespan are not yet available. Further research is needed in order to be able to calibrate the model and quantify the absolute change in service life taking into account countries' specific technological practices, bituminous mixtures types, and climatic conditions. Optimisation of the model regarding the reduction of the number and weighting of the most relevant project dependent variables is also needed.

1 Introduction

The service life of pavement surface courses is highly dependent on the construction process. A longer life span has an enormous impact on the carbon footprint of the road. A large number of parameters have to be controlled and kept at optimum during the transport, laying and compaction process.

The temperature of the asphalt mixture during laying and compaction process (roller passes) has the most critical effect on the uniformity of the degree of compaction and the evenness of the asphalt layer. Segregation and cooling of the asphalt mixture during transport reduces the life span of a pavement.

Contractors and road managers understand the benefits of new quality control techniques employed during transport, laying and compaction process. In WP2 a tool was developed to assess the impact of the quality of the construction process on the performance of pavements. The general aim of this work package was to implement the newly developed tool in practice. The tool was tested in real case pavement projects in Slovenia and the United Kingdom.

The 'real case' project in Slovenia conducted in May 2015 identified in detail the benefits of innovative techniques for control of pavement works. The tested devices for IR scanning of thermal profile - monitoring temperatures of asphalt during laying also allowed for measuring and recording of weather conditions and paver speed. The quality control programme, which is usually employed during asphalt laying, lacks the documenting of such information.

The second pilot project in England focused on combining the most promising techniques identified with the tool and comparing these to conventional methods.

In order to demonstrate the applicability of the proposed tool, it was decided to compare the lifespan prediction for the 'during contract phase' with that for the 'after construction phase 1' taking into account the results of usual scope of quality control and that for the 'after construction phase 2' taking into account the results obtained by the devices for automated monitoring of paving process.

The CONSISTED project was demonstrated within a workshop in Ljubljana to national experts. The aim of the workshop was to discuss the possible factors affecting the lifespan of a pavement and the weighting of these input parameters. With the help of a questionnaire, answered during the workshop, expert opinion was gathered and the results are presented in the report.

2 Test site in Slovenia

2.1 Description of test site in Slovenia

In order to demonstrate the applicability of the proposed tool a pilot project was carried out to demonstrate the potential improvements in transport, laying and compacting procedures achievable using the tool. In the project in Slovenia the innovative monitoring techniques employed during paving were used as well as the standard quality control techniques.

A 1.7 km long motorway section located in Slovenia near Celje was chosen for evaluation of the applicability of the tool. The evaluation focused on the quality of the top layer, which was, in this case, a 4 cm thick layer of Stone mastic asphalt with a polymer modified bitumen. The paving works of the top layer were performed on three non-consecutive days in May 2015 in good weather conditions. The motorway rehabilitation works were contracted to a prequalified contractor Pomgrad, d.d. offering the best price for the tendered works. The contractor used his own asphalt production works, equipment (paver and rollers) and an experienced asphalt laying team.

It was planned to demonstrate the possible gain in service life that can be obtained when using innovative quality control methods during the laying process in comparison to the usual quality control testing scope. Close monitoring of the paving process does not necessarily improve the quality of the current paving job, but analyses of weak spots and corrective measures may improve the road service life of the future projects. For example; temperature differences of asphalt mix that may lead to thermal segregation of the material can be determined during the job, however the countermeasures must be taken accordingly immediately.

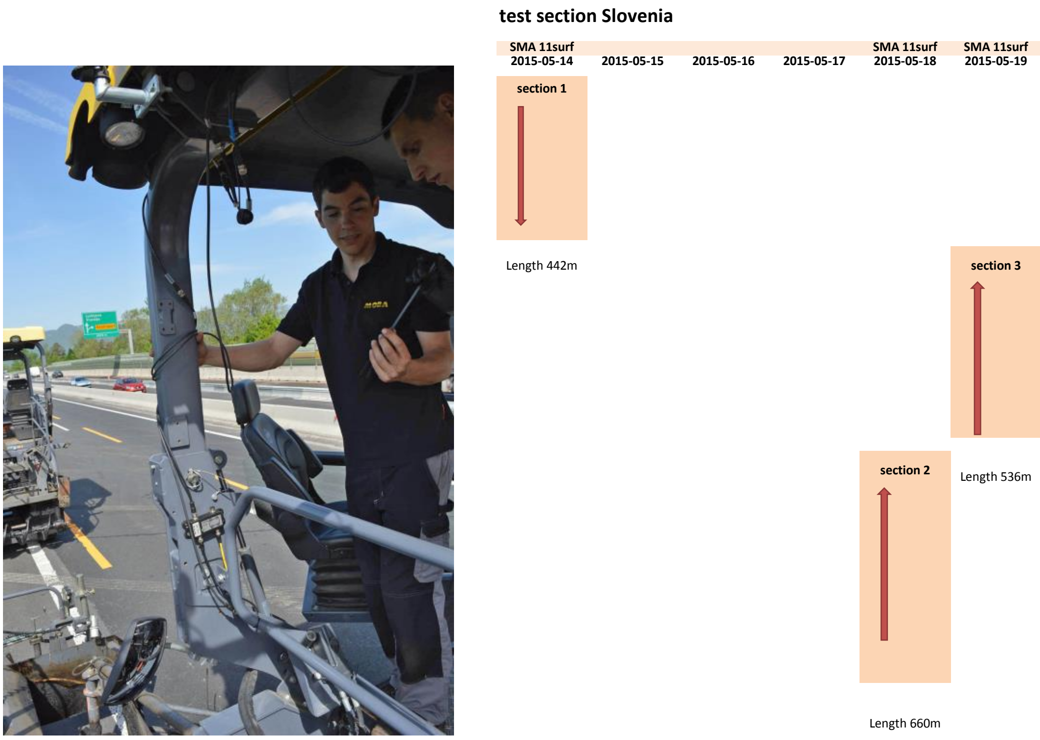

Figure 1: Time schedule and directions of paving of surface layers

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The contractor was responsible for the day to day supervision and quality control (QC). During the paving works the usual scope of QC testing was undertaken by the contractor's internal QC department, following the client's predefined programme. The tests consisted of checking the characteristics of the produced asphalt (samples were taken from the paver) and checking of the laid asphalt (i.e. the layer thickness, void content and densities of asphalt cores). The usual QC programme included control of asphalt densities at numerous locations using the nuclear method, and occasional checking of the temperature of the asphalt during paving using a hand-held thermometer. Since the quality control of asphalt is important for service life, some of the tests were also performed by third party laboratories, which in this case was ZAG Ljubljana. The usual scope of third party's QC testing comprises a small number of the same type of tests.

Apart from the usual QC testing scope, new innovative techniques were used to monitor the paving process on the investigated motorway section. For CONSISTEND project additional equipment was rented from MOBA Mobile Automation AG to monitor the laying process for the top layer. Mounting of the equipment on the paver by producer's experts is shown in figures 1, 2 and 3.

Figure 2: Mounting of the equipment on paver

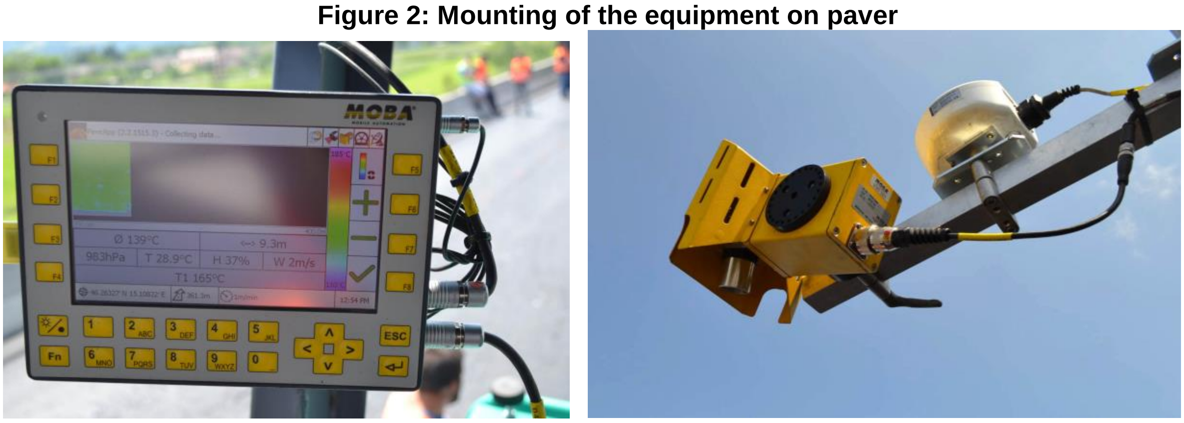


Figure 3: On-board computer and IR temperature scanner and GNSS antenna

The equipment PAVE-IR™ Scan enabled automated measurements and recording the asphalt temperature during paving in the paver auger, and immediately behind the screed by means of IR temperature scanning. This system records the temperature data, including GNSS position and weather data (ambient temperature, wind and humidity). The data is displayed on the monitor in real time. The actual paving process is shown in Figures 4 and 5. The weather conditions were good on all days of paving.

Figure 4: Echelon paving – 18th May 2015

Figure 5: Rollers at paving stage – 18th May 2015

The paving works of the top layer were performed on three non-consecutive days in May 2015 (see Figure 1). The 422m long section, which had been chosen for demonstration of tool results, was paved on 14th May 20015 in good weather conditions.

The total paving width of the road was 10 m; lane 1 (driving lane), lane 2 (overtaking lane) and hard shoulder. The top layer was, in this case, a 4 cm thick layer of Stone mastic asphalt with a polymer modified bitumen SMA11 PmB 45/80-65. A Vögele 2100 paver with a vibratory screed was employed for laying. HAMM and AMMAN rollers were used for compaction - four to six vibratory rollers were compacting the three lanes behind the paver (Figure 5)

Figure 6: Third party's control - cores of asphalt layer

Within the Contractor's quality control testing five samples of the produced asphalt mix SMA11 PmB 45/80-65 were tested on this road section. The measured temperature by handheld thermometer at paver auger was 170^{o}C on average. Two cores were drilled into the top layer after paving and the results of thickness of the top layer, void content, and density showed compliance with the specification.

The results obtained by the contractor's control and third party control during and after the construction process showed no discrepancies from the specification for the temperature of the asphalt during laying, the thickness of the layer, the void ratio, and densities. The overall conclusion was that the asphalt complied with the required characteristics. Such results are not surprising since the potentially under-compacted sections made up less than 1% of the pavement area, and were therefore difficult to detect.

2.2 Results of innovative quality control techniques

Each day the paver driver mounted the on-board computer (Figure 3a) and started the recording. The asphalt temperature during paving in the paver auger and immediately behind the screed was recorded with PAVE-IR™ Scan. The recorded information was displayed during the paving in real time. This system recorded also GNSS position and weather data (ambient temperature, wind and humidity). At the end of the day the on-board computer was dismantled and the recorded data was archived on a personal computer.

The data that was collected in the field was evaluated with the Pave Project Manager software (in our case Pave Project Manager v2.5 - test version). Areas with thermal segregation were detected and some are shown below. In Figure 7 is shown the thermal profile (at top part of the picture) and location and the direction of paving (at bottom part).

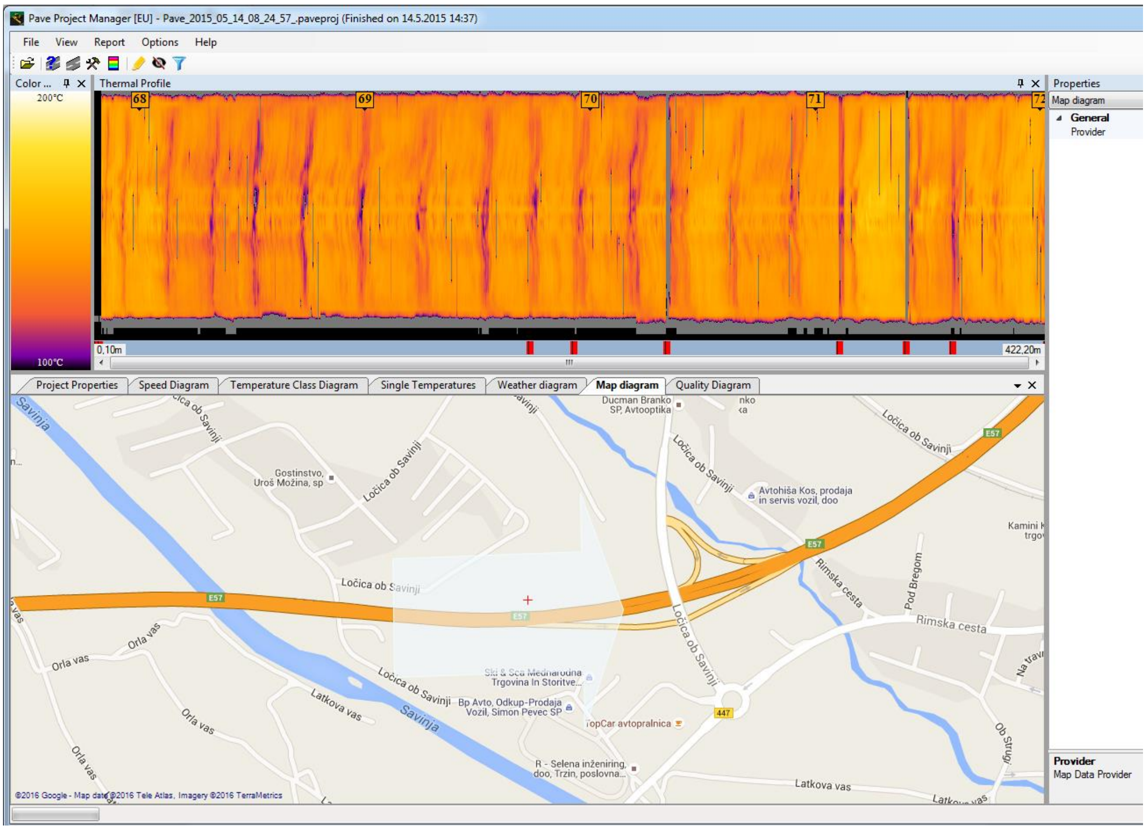


Figure 7: Location and direction of paving

In Figure 8 is shown the thermal profile of the entire 442m long road section (at top part) and asphalt mix temperature at paver auger (at bottom part).

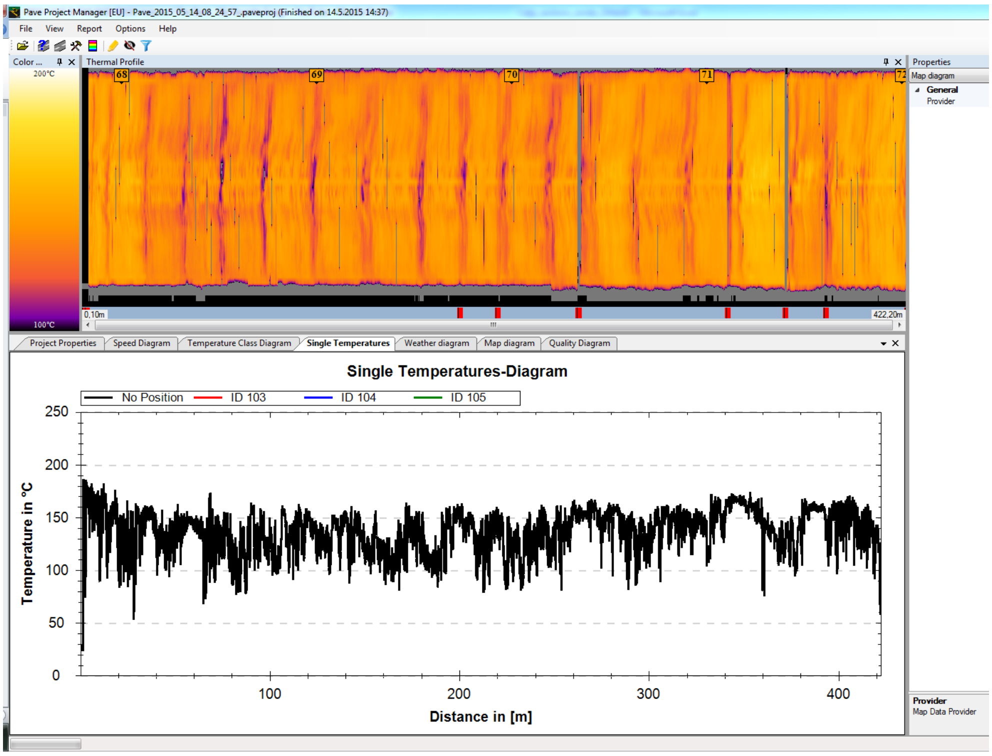


Figure 8: Minimum and maximum temperatures during paving

In Figure 9 is shown the thermal profile (at top part) and weather conditions at paver (at bottom part). The results of continuous monitoring showed that the weather conditions were good on all the paving days, at all times

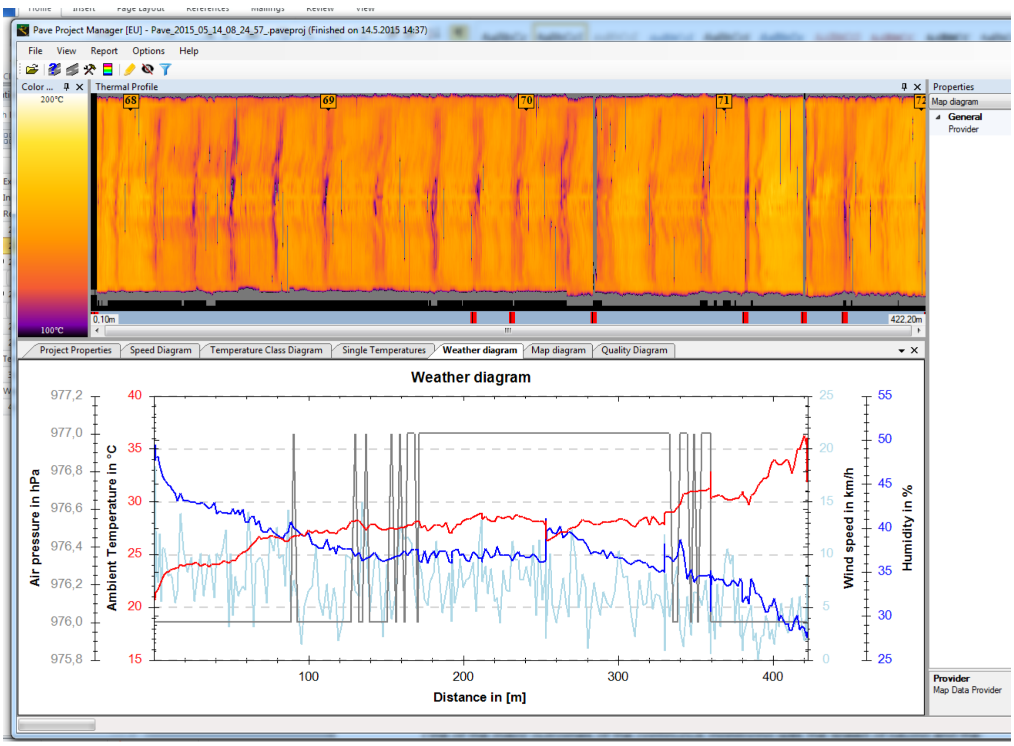


Figure 9: Actual weather conditions

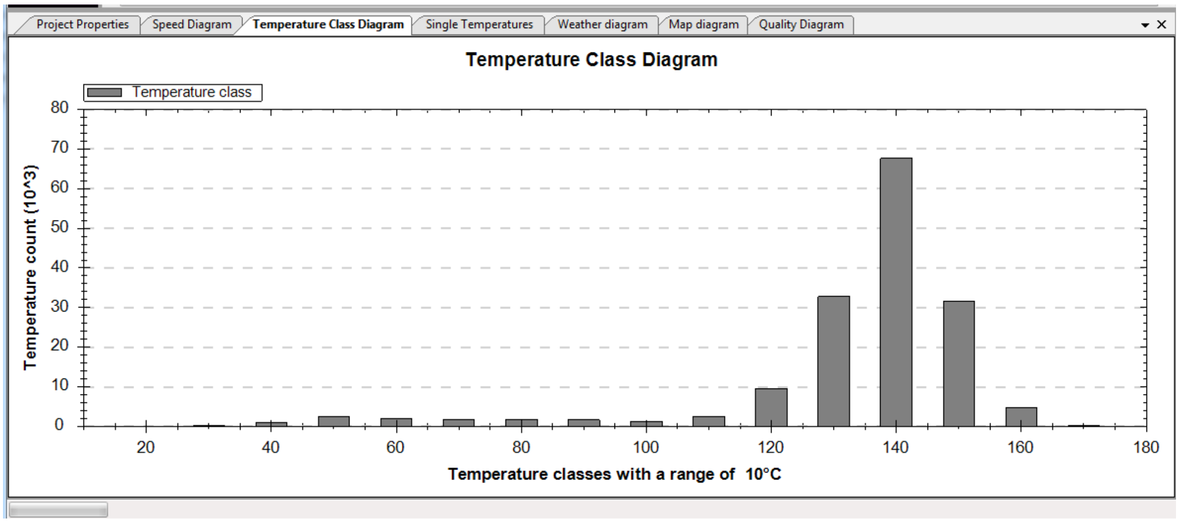


Figure 10: Temperature class diagram

In Figure 10 is shown the class diagram for the entire the entire 442m long road section. In Figure 11 is shown a 95m long section from the test section – the detailed thermal profile (at top part) and asphalt mix temperature at paver auger (at bottom part).

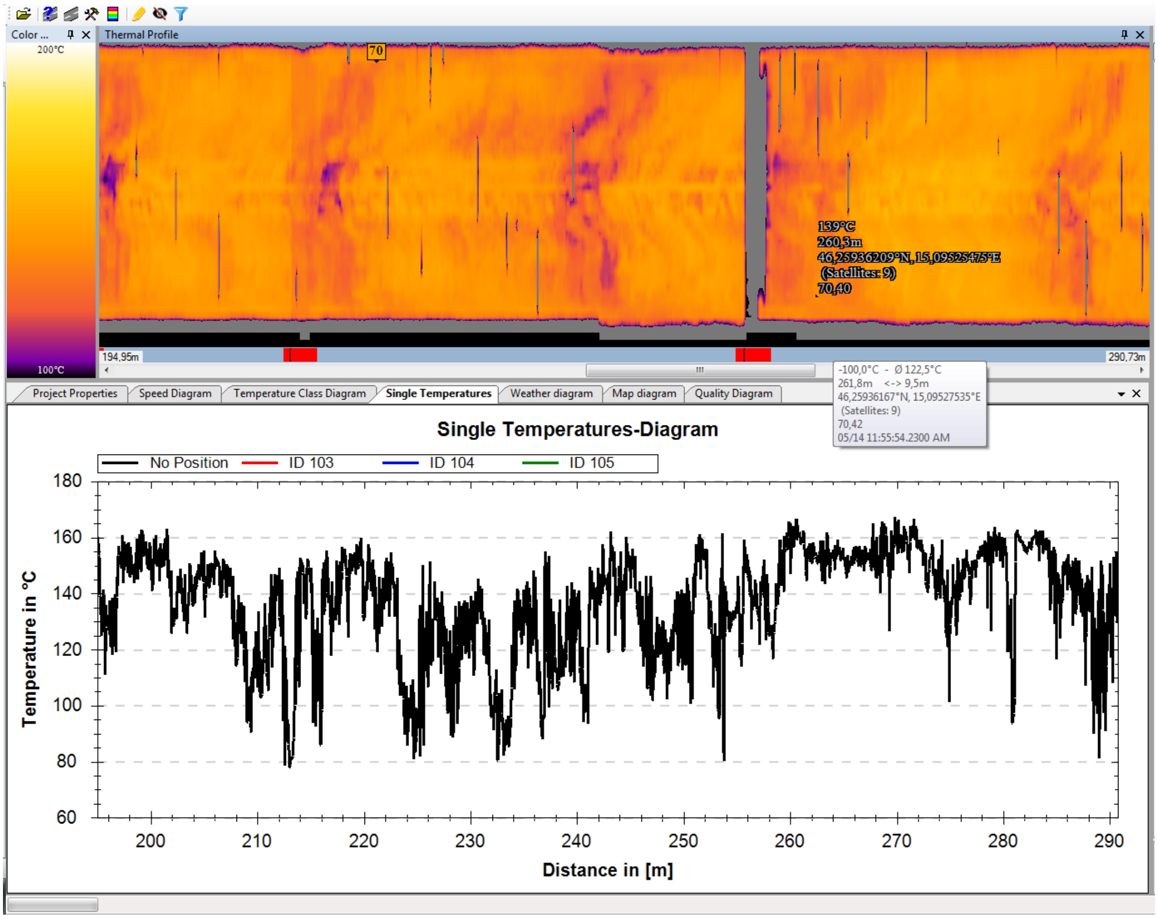


Figure 11: Detail – part of a road section

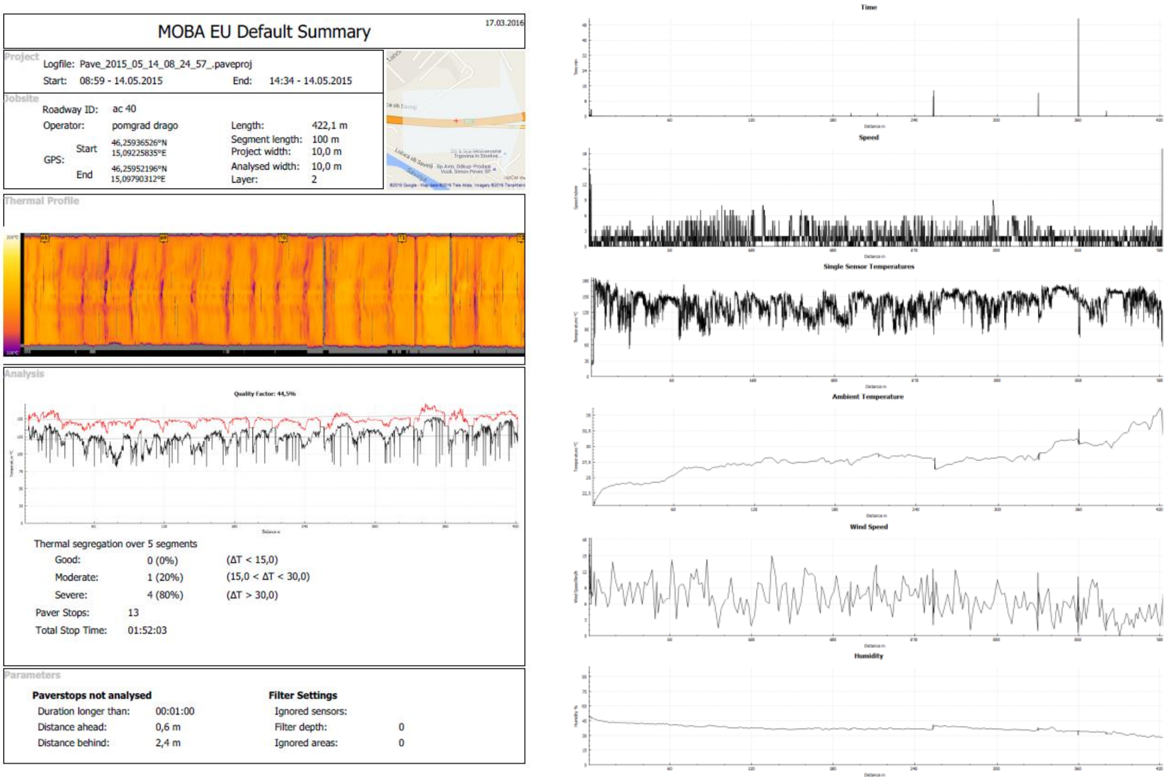


Figure 12: Report – example

In Figure 12 is shown an example of a report generated by the Pave Project Manager v2.5.Using this data, the system allows conclusions to be drawn about the quality of the asphalt. One of the outcomes of the continuous monitoring was the speed of paving and the number and duration of paver stops.

Table 1 Number of paver stops and suggested severity of thermal segregation

Stops on 422m long section	Number	Thermal segregation
Full stops of no more than 2 minutes	7	good
Full stops of 2 to 5 minutes	1	moderate
Full stops of 5 to 15 minutes	3	severe
Full stops of 15 to 30 minutes	0	
Full stops of 30 to 60 minutes	1	severe
Total number of paver stops	13	

The number and duration of paver stops could be employed in the CONSISTEND tool as a measurable input parameter. In this paving job there were 13 paver stops altogether. The temperature measurements in this job showed that during all paver stops of longer than 10 minutes the surface of the asphalt behind the paver cooled down significantly, despite the good weather conditions. Since it is impossible to access the surface very close to the paver with rollers, these sections were compacted when the paver had started moving again at an asphalt surface temperature lower than the 'optimum'. In Table 1 is given an overview of the paver stops and assumed severity of thermal segregation.

On the 422m long section the software detected 4 segments where thermal segregation was described as 'severe' (see Table 1). In reality these segments are very short and therefore difficult to detect within the usual scope of quality control testing.

With the GPS positioning and IR temperature scanning equipment it was possible to record the temperature profile for the entire project. The visualisation of thermal profile and other data (paver speed, single temperature sensor) was easy to understand. With post processing in the office it is possible to re-view the entire paving procedure and analyse the parameters influencing the quality. Using the records from the field, the system allows the Contractor to draw conclusions about the quality of the asphalt laying process and making improvements. The documented data may serve as evidence of a precision job.

2.3 Implementation of the tool

The pilot pavement project was conducted to implement the newly developed tool in practice. In order to demonstrate the applicability of the proposed tool, it was decided to compare the lifespan prediction for the

1) 'during contract phase' (that is before the actual construction) with that for the
2) 'after construction phase 1' taking into account the results of usual scope of quality control and that for the
3) 'after construction phase 2' taking into account the results obtained by the innovative equipment for automated monitoring of temperature during paving process.

The tool was used to evaluate the impact of the monitored parameters on the calculated lifespan of the investigated pavement. For evaluation of the possible lifespan, the 422 m long test section, described in section 2.2, was chosen.

2. Input		
2.1 General		
Country:	Slovenia	
This implies the model takes into account:	AC11surf B50/70 A2; TSC 06.300 /06.410:2009; 5 cm	
Length of section [m]:	420	
This tool is used:	During contract phase	
2.2 Conditions during transport, laying and construction		
2.2.1 Temperature of material:	estimated average value	
a. temperature during transport	180	°C
b. temperature during laying	150	°C
c. temperature during compaction	140	°C
2.2.2 Weather:	estimated average value	
a. wind speed during laying	0	km/h
b. ambient temperature during laying	25	°C
c. rainfall during laying	no	
d. wind speed during compaction	0	km/h
e. ambient temperature during compaction	25	°C
f. rainfall during compaction	no	
2.2.3 Compaction:	estimated average value	
a. void content after compaction	4	%
b. number of roller passes during compaction	6	nr
2.2.4 Equipment:		
a. during transport (assume average haulage distance)	0	% of trucks are trucks **without insulation**
	100	% of trucks are trucks **with thermal insulation**
	0	% of trucks are **temparature conditioned**
	100	
b. during laying	100	% of pavers are **normal pavers**
	0	% of pavers are **pavers with IR and/or GPS**
	100	
c. during compaction	0	% of rollers are **lightweight rollers**
	100	% of rollers are **commonly used rollers**
	0	% of rollers are **rollers with IR and/or GPS**
	100	
2.2.5 Workmanship:		
a. during laying	0	% of workers are **inexperienced**
	0	% of workers are **trained workers**
	100	% of workers are **experienced workers**
	100	
b. during compaction	0	% of workers are **inexperienced**
	0	% of workers are **trained workers**
	100	% of workers are **experienced workers**
	100	
2.2.6 Travel time and delays (with an insulated truck):	estimated average value	
a. haulage time from the plant (transport)	45	minutes
b. queue to offload (time delay incurred on site) (laying)	0	minutes
c. waiting at paver for next load (compaction)	0	minutes

Figure 13: Input for the 'during contract phase' – part 1

2.2.7 Joints - longitudal joints:		
a. construction	0	% of joints is formed cold and unpainted
	10	% of joints is formed cold trimmed and painted
	90	% of joints is formed by hot matching
	100	
2.2.8 Interlayer bond:	estimated average value	
a. amount	0,6	kg/m2
2.3 Quality control methods used		
2.3.1 Temperature of material:		
a. during transport	insulated truck	
b. during laying and compaction	no method	
c. measuring methods	point measurement of temperature	
2.3.2 Weather:		
-		
2.3.3 Compaction:		
a. variability of void content	standard roller - best achievable compaction	
b. variability of roller passes	standard roller	
2.3.4 Travel time and delays (with an insulated truck):		
a. during transport	standard procudure - standard practice	
b. during laying	standard procudure - standard practice	
c. during compaction	standard procudure - standard practice	
2.3.5 Interlayer bond:		
a. course of information	test rate of application - best practice	

Figure 14: Input for the ‘during contract phase’ – part 2

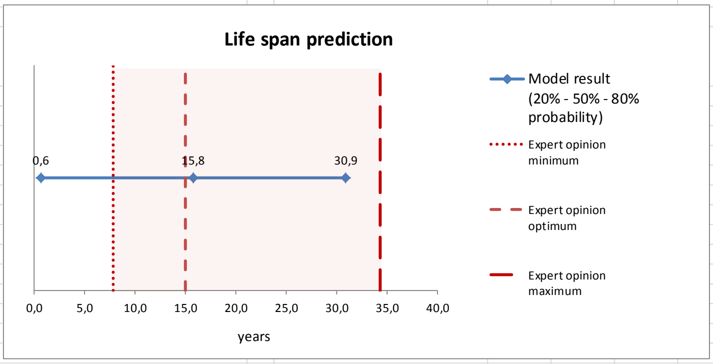
Several project dependent parameters need to be entered into the tool input file. For the ‘during contract phase’ that refers to the procurement phase, the input parameters need to be assumed realistically, depending on the expected time of year of pavement works (weather conditions), known location of the asphalt plant (haulage times), contractor’s equipment (thermal insulation on trucks, shuttle buggy, IR temperature measurements) etc.. The chosen input parameters for the ‘during contract phase’ are shown in Figure 13 and Figure 14.

The ‘during contract phase’ was simulated, taking into account:

- good weather conditions (parameters for ‘no rain’, ‘ambient temperature’ 25 ^{o}C, ‘wind’ 0 km/h),
- ‘asphalt temperatures during transport’ (180 ^{o}C±0 ^{o}C), laying (150 ^{o}C ±0 ^{o}C), and compaction (140 ^{o}C ±0 ^{o}C),
- parameter for ‘experience of asphalting team’,
- an ‘average transport time’ of 45 minutes,
- 90% of joints hot matched, etc.

The model results obtained by using the tool for the ‘during contract phase’ showed a ‘mean predicted lifespan’ of 15.8 years, as it is shown in Figure 15.

Model result		
mean predicted life span	15,8	years
minimum lifespan (20% lower boundary)	0,6	years
maximum lifespan (80% upper boundary)	30,9	years



Model assumptions		
2.1 General		
Country:	Slovenia	
This implies the model takes into account:	AC11surf B50/70 A2; TSC 06.300 /06.410:2009; 5 cm	
Length of section [m]:	420	
This tool is used:	During contract phase	
2.2 Conditions during transport, laying and construction		
2.2.1 Temperature of material:		
a. temperature during transport	180	°C
b. temperature during laying	150	°C
c. temperature during compaction	140	°C
2.2.2 Weather:		
a. wind speed during laying	0	km/h
b. ambient temperature during laying	25	°C
c. rainfall during laying	no	
d. wind speed during compaction	0	km/h
e. ambient temperature during compaction	25	°C
f. rainfall during compaction	no	
2.2.3 Compaction:		
a. void content after compaction	4	%
b. number of roller passes during compaction	6	nr
2.2.4 Equipment:		
a. during transport (assume average haulage distance)	0	% of trucks are trucks **without insulation**
	100	% of trucks are trucks **with thermal insulation**
	0	% of trucks are **temparature conditioned**
b. during laying	100	% of pavers are **normal pavers**
	0	% of pavers are **pavers with IR and/or GPS**
c. during compaction	0	% of rollers are **lightweight rollers**
	100	% of rollers are **commonly used rollers**
	0	% of rollers are **rollers with IR and/or GPS**
2.2.5 Workmanship:		
a. during laying	0	% of workers are **inexperienced**
	0	% of workers are **trained workers**
	100	% of workers are **experienced workers**
b. during compaction	0	% of workers are **inexperienced**
	0	% of workers are **trained workers**
	100	% of workers are **experienced workers**
2.2.6 Travel time and delays (with an insulated truck):		
a. haulage time from the plant (transport)	45	minutes
b. queue to offload (time delay incurred on site) (laying)	0	minutes
c. waiting at paver for next load (compaction)	0	minutes
2.2.7 Joints - longitudal joints:		
a. construction	0	% of joints is formed **cold and unpainted**
	10	% of joints is formed **cold trimmed and painted**
	90	% of joints is formed **by hot matching**
2.2.8 Interlayer bond:		
a. amount	0,6	kg/m2

Figure 15: Results obtained by using the tool for the 'during contract phase'

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Then the ‘after construction phase 1’ was simulated, taking into account positive results of the usual quality control;

- assuming good weather conditions (no rain, ambient temperature 25 ^{o}C, wind 0 km/h),
- the same project dependent values for
  - ‘asphalt temperatures’,
  - parameter for ‘experience of asphalting team’,
  - and an ‘average transport time’ of 45 minutes.

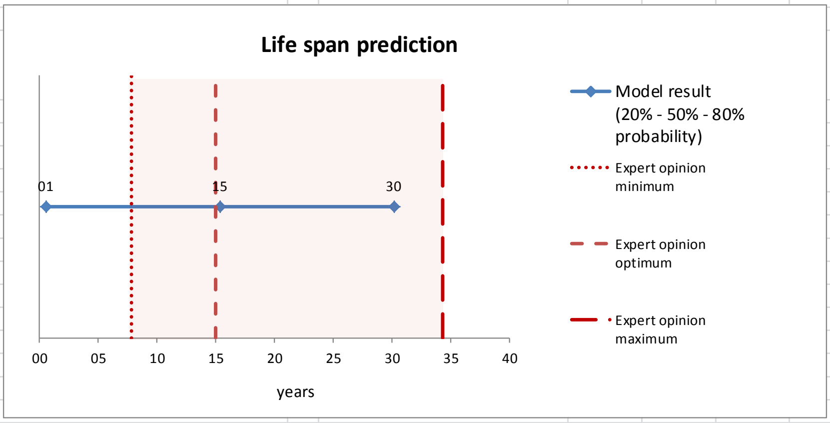
The input parameters for the ‘after construction phase 1’ are shown in Figure 16.

The model results obtained by using the tool for the ‘after construction phase 1’ showed a ‘mean predicted lifespan’ of 15.4 years, as it is shown in Figure 17.

2. Input				
2.1 General				
Country:	Slovenia			
This implies the model takes into account:	AC11surf B50/70 A2; TSC 06.300 /06.410:2009; 5 cm			
Length of section [m]:	420			
This tool is used:	After construction			
2.2 Conditions during transport, laying and construction				
2.2.1 Temperature of material:	average value		st.dev. (if measured)	
a. temperature during transport	180	°C	0	°C
b. temperature during laying	150	°C	0	°C
c. temperature during compaction	140	°C	0	°C
2.2.2 Weather:	average value		st.dev. (if measured)	
a. wind speed during laying	0	km/h	0	km/h
b. ambient temperature during laying	25	°C	0	°C
c. rainfall during laying	no		-	
d. wind speed during compaction	0	km/h	0	km/h
e. ambient temperature during compaction	25	°C	0	°C
f. rainfall during compaction	no		-	
2.2.3 Compaction:	average value		st.dev. (if measured)	
a. void content after compaction	4	%	2	%
b. number of roller passes during compaction	6	nr	2	nr
2.2.4 Equipment:				
a. during transport (assume average haulage distance)	0	% of trucks are trucks **without insulation**		
	100	% of trucks are trucks **with thermal insulation**		
	0	% of trucks are **temparature conditioned**		
	100			
b. during laying	100	% of pavers are **normal pavers**		
	0	% of pavers are **pavers with IR and/or GPS**		
	100			
c. during compaction	0	% of rollers are **lightweight rollers**		
	100	% of rollers are **commonly used rollers**		
	0	% of rollers are **rollers with IR and/or GPS**		
	100			
2.2.5 Workmanship:				
a. during laying	0	% of workers are **inexperienced**		
	0	% of workers are **trained workers**		
	100	% of workers are **experienced workers**		
	100			
b. during compaction	0	% of workers are **inexperienced**		
	0	% of workers are **trained workers**		
	100	% of workers are **experienced workers**		
	100			
2.2.6 Travel time and delays (with an insulated truck):	average value		st.dev. (if measured)	
a. average haulage time from the plant (transport)	45	minutes	0	minutes
-				
-				
b. paver stops	0	nr of full stops of **30 to 60 minutes**		
	0	nr of full stops of **15 to 30 minutes**		
	0	nr of full stops of **5 to 15 minutes**		
	0	nr of full stops of **2 to 5 minutes**		
	1	nr of full stops of no more than **2 minutes**		
2.2.7 Joints - longitudal joints:				
a. construction	0	% of joints is formed cold and unpainted		
	10	% of joints is formed cold trimmed and painted		
	90	% of joints is formed by hot matching		
	100			
2.2.8 Interlayer bond:	average value		st.dev. (if measured)	
a. amount	0,6	kg/m2	x	please answer question a in section 2.3.5

Figure 16: Input for the ‘after construction phase 1’

Model result		
mean predicted life span	15,4	years
minimum lifespan (20% lower boundary)	0,6	years
maximum lifespan (80% upper boundary)	30,2	years



Model assumptions		
2.1 General		
Country:	Slovenia	
This implies the model takes into account:	AC11surf B50/70 A2; TSC 06.300 /06.410:2009; 5 cm	
Length of section [m]:	420	
This tool is used:	After construction	
2.2 Conditions during transport, laying and construction		
2.2.1 Temperature of material:		
a. temperature during transport	180	°C
b. temperature during laying	150	°C
c. temperature during compaction	140	°C
2.2.2 Weather:		
a. wind speed during laying	0	km/h
b. ambient temperature during laying	25	°C
c. rainfall during laying	no	
d. wind speed during compaction	0	km/h
e. ambient temperature during compaction	25	°C
f. rainfall during compaction	no	
2.2.3 Compaction:		
a. void content after compaction	4	%
b. number of roller passes during compaction	6	nr
2.2.4 Equipment:		
a. during transport (assume average haulage distance)	0	% of trucks are trucks **without insulation**
	100	% of trucks are trucks **with thermal insulation**
	0	% of trucks are **temparature conditioned**
b. during laying	100	% of pavers are **normal pavers**
	0	% of pavers are **pavers with IR and/or GPS**
c. during compaction	0	% of rollers are **lightweight rollers**
	100	% of rollers are **commonly used rollers**
	0	% of rollers are **rollers with IR and/or GPS**
2.2.5 Workmanship:		
a. during laying	0	% of workers are **inexperienced**
	0	% of workers are **trained workers**
	100	% of workers are **experienced workers**
b. during compaction	0	% of workers are **inexperienced**
	0	% of workers are **trained workers**
	100	% of workers are **experienced workers**
2.2.6 Travel time and delays (with an insulated truck):		
a. haulage time from the plant (transport)	45	minutes

Figure 17: Results obtained by using the tool for the 'after construction phase 1'

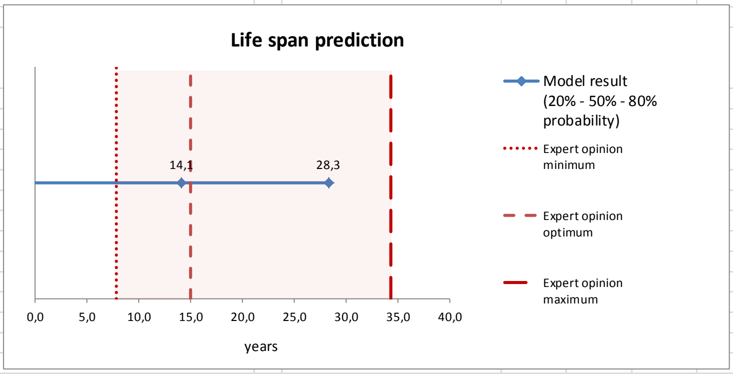
Finally the ‘after construction phase 2’ was simulated, taking into account the information based on new quality control techniques during construction - paver speed monitoring, asphalt temperature monitoring, and the weather report. Longer transport times, larger deviations in the laying temperatures, and some wind were actually measured. Good weather conditions - parameters for ‘no rain’, an average ‘ambient temperature’ of 28 ^{o}C (±7 ^{o}C standard deviation), a wind of 7 km/h±5 km/h were input, as well as measured ‘asphalt temperatures’ during laying (150 ^{o}C ±25 ^{o}C) and compaction (140 ^{o}C ±25 ^{o}C). The parameter for ‘average transport time’ was changed to 90 minutes (±45 minutes), whereas the other parameters were unchanged.

The input parameters for the ‘after construction phase 2’ are shown in Figure 18.
The model results obtained by using the tool for the ‘after construction phase 2’ showed a ‘mean predicted lifespan’ of 14.1 years, as it is shown in Figure 19.

2. Input				
2.1 General				
Country:	Slovenia			
This implies the model takes into account:	AC11surf B50/70 A2; TSC 06.300 /06.410:2009; 5 cm			
Length of section [m]:	420			
This tool is used:	After construction			
2.2 Conditions during transport, laying and construction				
2.2.1 Temperature of material:	average value		st.dev. (if measured)	
a. temperature during transport	180	°C	25	°C
b. temperature during laying	150	°C	25	°C
c. temperature during compaction	140	°C	25	°C
2.2.2 Weather:	average value		st.dev. (if measured)	
a. wind speed during laying	10	km/h	10	km/h
b. ambient temperature during laying	28	°C	10	°C
c. rainfall during laying	no		-	
d. wind speed during compaction	10	km/h	10	km/h
e. ambient temperature during compaction	28	°C	10	°C
f. rainfall during compaction	no		-	
2.2.3 Compaction:	average value		st.dev. (if measured)	
a. void content after compaction	4	%	2	%
b. number of roller passes during compaction	6	nr	2	nr
2.2.4 Equipment:				
a. during transport (assume average haulage distance)	0	% of trucks are trucks **without insulation**		
	100	% of trucks are trucks **with thermal insulation**		
	0	% of trucks are **temparature conditioned**		
	100			
b. during laying	100	% of pavers are **normal pavers**		
	0	% of pavers are **pavers with IR and/or GPS**		
	100			
c. during compaction	0	% of rollers are **lightweight rollers**		
	100	% of rollers are **commonly used rollers**		
	0	% of rollers are **rollers with IR and/or GPS**		
	100			
2.2.5 Workmanship:				
a. during laying	0	% of workers are **inexperienced**		
	0	% of workers are **trained workers**		
	100	% of workers are **experienced workers**		
	100			
b. during compaction	0	% of workers are **inexperienced**		
	0	% of workers are **trained workers**		
	100	% of workers are **experienced workers**		
	100			
2.2.6 Travel time and delays (with an insulated truck):	average value		st.dev. (if measured)	
a. average haulage time from the plant (transport)	120	minutes	60	minutes
-				
-				
b. paver stops	0	nr of full stops of **30 to 60 minutes**		
	0	nr of full stops of **15 to 30 minutes**		
	0	nr of full stops of **5 to 15 minutes**		
	0	nr of full stops of **2 to 5 minutes**		
	1	nr of full stops of no more than **2 minutes**		
2.2.7 Joints - longitudal joints:				
a. construction	0	% of joints is formed cold and unpainted		
	10	% of joints is formed cold trimmed and painted		
	90	% of joints is formed by hot matching		
	100			
2.2.8 Interlayer bond:	average value		st.dev. (if measured)	
a. amount	0,6	kg/m2	x	please answer question a in section 2.3.5

Figure 18: Input for the ‘after construction phase 2’

Model result		
mean predicted life span	14,1	years
minimum lifespan (20% lower boundary)	0,0	years
maximum lifespan (80% upper boundary)	28,3	years



Model assumptions		
2.1 General		
Country:	Slovenia	
This implies the model takes into account:	AC11surf B50/70 A2; TSC 06.300 /06.410:2009; 5 cm	
Length of section [m]:	420	
This tool is used:	After construction	
2.2 Conditions during transport, laying and construction		
2.2.1 Temperature of material:		
a. temperature during transport	180	°C
b. temperature during laying	150	°C
c. temperature during compaction	140	°C
2.2.2 Weather:		
a. wind speed during laying	7	km/h
b. ambient temperature during laying	28	°C
c. rainfall during laying	no	
d. wind speed during compaction	7	km/h
e. ambient temperature during compaction	28	°C
f. rainfall during compaction	no	
2.2.3 Compaction:		
a. void content after compaction	4	%
b. number of roller passes during compaction	6	nr
2.2.4 Equipment:		
a. during transport (assume average haulage distance)	0	% of trucks are trucks **without insulation**
	100	% of trucks are trucks **with thermal insulation**
	0	% of trucks are **temparature conditioned**
b. during laying	100	% of pavers are **normal pavers**
	0	% of pavers are **pavers with IR and/or GPS**
c. during compaction	0	% of rollers are **lightweight rollers**
	100	% of rollers are **commonly used rollers**
	0	% of rollers are **rollers with IR and/or GPS**
2.2.5 Workmanship:		
a. during laying	0	% of workers are **inexperienced**
	0	% of workers are **trained workers**
	100	% of workers are **experienced workers**
b. during compaction	0	% of workers are **inexperienced**
	0	% of workers are **trained workers**
	100	% of workers are **experienced workers**
2.2.6 Travel time and delays (with an insulated truck):		
a. haulage time from the plant (transport)	90	minutes
b. paver stops	0	nr of full stops of 30 to 60 minutes
-	0	nr of full stops of 15 to 30 minutes
	0	nr of full stops of 5 to 15 minutes
	0	nr of full stops of 2 to 5 minutes
	1	nr of full stops of no more than 2 minutes
2.2.7 Joints - longitudal joints:		
a. construction	0	% of joints is formed **cold and unpainted**
	10	% of joints is formed **cold trimmed and painted**
	90	% of joints is formed **by hot matching**
2.2.8 Interlayer bond:		
a. amount	0,6	kg/m2

Figure 19: Results obtained by using the tool for the ‘after construction phase 2’

The results showed that the application of advanced quality control techniques during construction can provide a much more detailed and more reliable insight into the quality of the actual transport, laying and compaction process, and thus into its influence on the pavement lifespan prediction. However, this quality control technique cannot provide measured results for all the input parameters of the tool.

Results of lifespan prediction with the tool demonstrate that the mean value of the predicted lifespan lies between the minimum and maximum lifespan, as expected.

However, the calculated lifespan (15.8 years) for ‘during contract phase’ is shorter than expected, since good paving conditions, experienced team and no detrimental deviations were considered.

Results of lifespan prediction for ‘after construction phase 1’ with the tool demonstrate that the mean value of the predicted lifespan is shorter (15.4 years) than for ‘during contract phase’.

Results of lifespan prediction for ‘after construction phase 2’ with the tool demonstrate that the mean value of the predicted lifespan is shorter (14.1 years) than for ‘after construction phase 1’. This was anticipated since some of the parameters were more unfavourable (e.g. longer transport time, deviations of asphalt mix temperatures). However, the change in mean value of the lifespan prediction is relatively small, and smaller than expected by the experts in the CONSISTEND project team. The relatively limited response of the model to change in project values of the input parameters can be explained by the summation of the influence of the degradation factors in the model, in combination with the high number (twenty one) of input parameters.

To increase the response of the model to a change in values of the input parameters, significantly less input parameters should be defined in a next version of the tool. Moreover the summation of influence of the input parameters is not in all cases desired. It was proposed to introduce weighting factors to individual input parameters.

3 Test site in UK

3.1 Description of test site in the UK

Versions of the intelligent equipment are factory fitted to several machines operated by different companies in the UK and used on a regular basis over a variety of contracts. One major issue identified is that there is a huge amount of information generated over the course of a single day which needs to be verified and interrogated to be of any value. Currently there is little or no drive from the client side for this information so much of it is collected and then not used. Some work is going on to devise programmes that can do all the interrogation and produce meaningful reports but this is in the early stages and some of this output is shown later in this section.

The contract chosen as a test site was selected as the material was being laid with a paver fitted with the equipment and the contract is a long term new build motorway where the contractor has to undertake testing and supply those results for most of the tests discussed and built in to the tool.

The contract is in the North of England and is a new build motorway to replace a current dual carriageway section of the A1 in Yorkshire. The new road will be designated the A1M while some sections of the old road will be retained as local and a non-motorway route. The overall length of the section is 20 km comprising 3 lanes in each direction plus hard shoulders. The contract commenced in May 2015 and is due for completion in April 2017. The main contractor is A1D2B and the surfacing sub-contractor is Aggregate Industries. The build-up of the road is as follows:

- 320mm CBGM (Cement Bound Granular Mixtures)
- 80mm AC 20 BC
- 40mm AC 14 SC

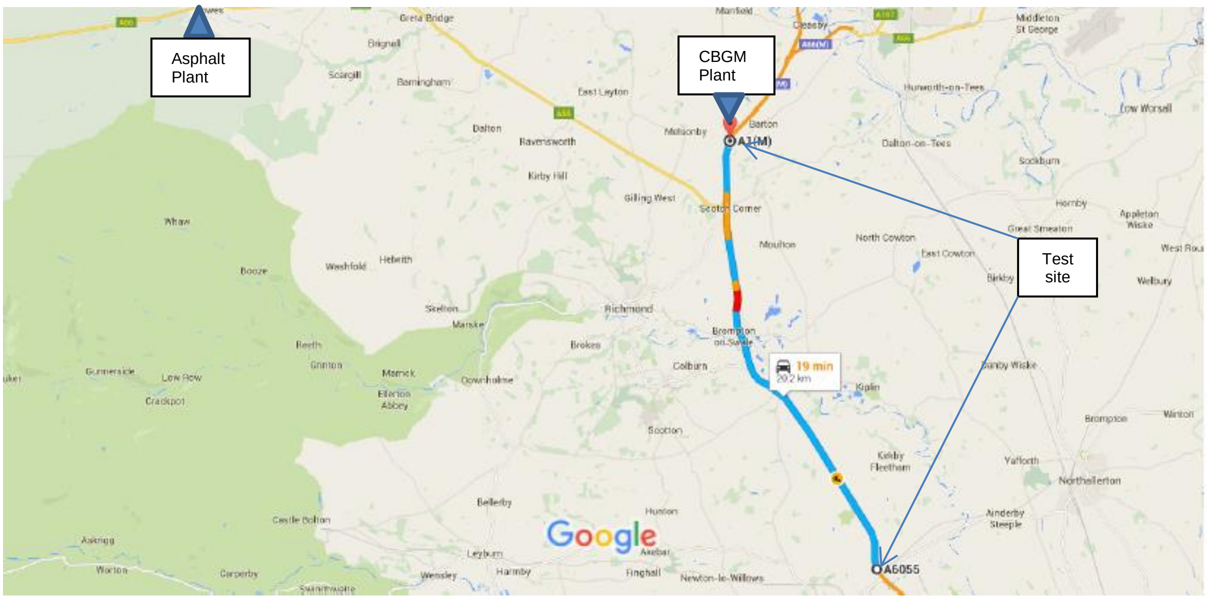


Figure 20: Site location

The base course is a 20mm Heavy Duty Macadam 40/60 design mix and the surface course is 14mm Hitex which is an Aggregate Industries proprietary thin surfacing material.

The CBGM plant is on the north end of the site at Barton while the asphalt plant is based in a quarry which is 28km North West of the north end of the site in Bowes. Both of these plants are operated by Aggregate Industries.

3.2 Site Equipment

Figure 21: shows the paver in use on this site together with the equipment fitted to take all of the measurements.

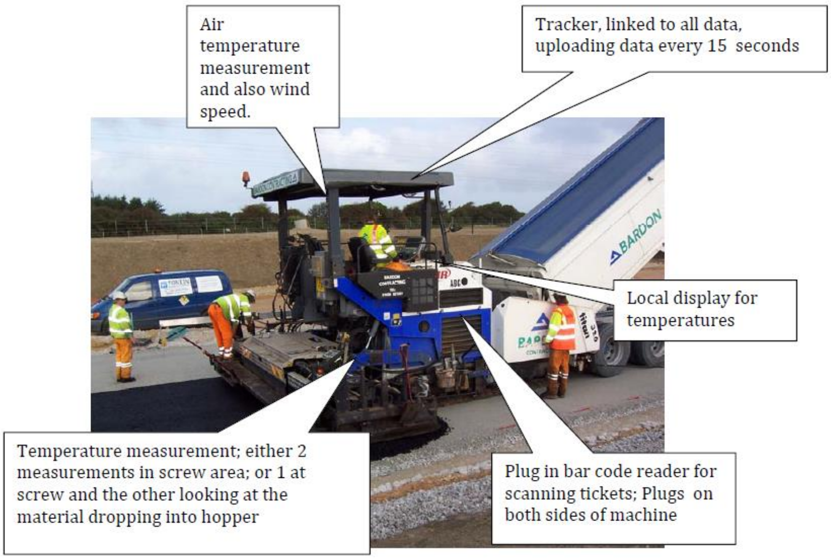


Figure 21: Site paving equipment

Figure 22: Digital screen

Figure 22 shows the digital screen used to enable the operatives to monitor the readings and ensures that the laying and material parameters are met. Figure 23 shows the digital screen mounted on the paving machine.

Figure 23: Digital screen on paver

Figure 24: GPS antennae

Figure 24 shows the GPS antennae mounted on the roof of the paver together with the wind speed and air temperature measurement equipment.

3.3 Reports from test site

On the day used for the monitoring of the information collected from the paving machine a total tonnage of 324 tonnes of an AC20mm dense binder course 40/50 pen was supplied. The ambient temperature was between9 ºC and 12ºC, the air pressure between 1005 and 1010, the humidity between 62.1% and 77.8%, the wind speed between 5 mph and 17.19mph with a gust up to 30.04mph and there were no delays in the supply of the material. The summary report from the system is shown in Figure 25 with a custom generated report of the same information shown in Figure 26. The information is only a summary of what is collected with the time and positioning taken when the supply vehicle delivery ticket bar code is scanned into the system. The custom report is a prototype report to make the information supplied from the system more user friendly. Further work is needed to fine tune this report.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Site:	21381130 - SCOTCH CORNER											This report is issued as an uncontrolled Copy!						
2	Paver ID:	206424											All originals are held by Highway Data Systems Ltd						
3	Date:	20/03/2015																	
4	Job No:	3977687																	
5	Report Nc	K15/001/200315/01																	
6																			
7	Ticket No	Registration	Plant	Material	Tonnage	Total Ton	Load Tim	longitude	latitude	Distance	Material Temp (°(	Time Logg	Comments		Time	Ambient Tem	Air Pressur	Humidity	Wind Speed
8	69048681	NX13BXP	Hulands	AC 20 den	19.48	19.48	720	-1.66783	54.435	36.3	184	08:30:35			08:02:41	9	1010	77.8	5
9	69049609	PN57OKX	Hulands	AC 20 den	19.52	39	813	-1.66745	54.43348	208	177	09:44:28			08:30:35	11	1010	70.3	4.98
10	69049812	CU05CWG	Hulands	AC 20 den	19.84	58.84	825	-1.66686	54.43108	401	167	10:50:11			09:02:32	11	1010	63.8	4.55
11	69049944	NU11ZXT	Hulands	AC 20 den	19.7	78.54	831	-1.66673	54.43057	431.1	168	10:58:03			09:33:20	11	1009	65.6	4.61
12	69050104	NX14UOE	Hulands	AC 20 den	20.1	98.64	839	-1.66651	54.42971	496.7	171	11:21:06			09:59:25	15	1010	64.9	3.75
13	69050963	NX59BNN	Hulands	AC 20 den	19.16	117.8	927	-1.6664	54.42925	513.9	178	11:27:13			10:31:41	15	1010	62.1	2.57
14	69051016	AE03UDW	Hulands	AC 20 den	19.86	137.66	931	-1.66618	54.42836	530.8	182	11:37:34			11:00:02	13	1010	65.7	11.19
15	69051205	NX09DYD	Hulands	AC 20 den	19.5	157.16	943	-1.66785	54.43488	598.8	168	12:24:17			11:27:13	12	1010	70.3	11.19
16	69053562	SK06JRG	Hulands	AC 20 den	19.58	176.74	1208	-1.66743	54.43317	755.5	164	13:09:38			11:58:25	12	1008	67.9	4.28
17	69053747	NX14UOE	Hulands	AC 20 den	19.38	196.12	1221	-1.66729	54.4326	787.2	168	13:38:02			12:29:16	12	1008	66.8	7.82
18	69054011	NX04LWD	Hulands	AC 20 den	19.76	215.88	1238	-1.66729	54.4326	787.2	173	13:38:05			12:57:57	12	1007	65.2	12.89
19	69054162	NX06DVV	Hulands	AC 20 den	19.62	235.5	1251	-1.66721	54.4323	817.6	178	13:48:27			13:28:20	12	1007	60.3	30.04
20	69054713	NX59BNN	Hulands	AC 20 den	19.44	254.94	1331	-1.66673	54.43033	964	166	14:49:20			14:00:19	13	1007	59.7	10.39
21	69053951	YJ55LUB		AC 20 den	10.12	265.06		-1.66663	54.42993	975.4	170	14:59:45			14:27:51	12	1007	61.9	13.87
22	69053575	N6NBT		AC 20 den	19.68	284.74		-1.66659	54.42978	984.2	172	15:03:16			15:00:28	12	1007	65.9	13.8
23	69055733	NX14UOE	Hulands	AC 20 den	19.52	304.26	1442	-1.66631	54.42862	1047.3	183	15:41:38			15:27:12	12	1007	65.1	12.95
24	69055954	NX04LWD	Hulands	AC 20 den	19.6	323.86	1500	-1.66796	54.43507	1131.3	184	16:09:23			16:00:03	12	1005	59.9	9.76
25															16:29:57	11	1005	64	17.19
26					323.86										17:03:04	11	1005	68.1	16.9
27																			
28																12.0	1008.0	65.5	10.4
29																			

Figure 25: System report

Highway Data Systems

Daily Laying Record

Page 1of 16

Site: 21381130 - SCOTCH CORNER
Paver ID: 206424
Date: 20/03/2015
Job No: 3977687
Report No: K15/001/200315/01

Ticket No	Registration	Plant	Material	Tonnage	Total Ton	Load Time	longitude	latitude	Distance (m)	Material Temp (°C)	Time Logged	Comments
69048681	NX13BXP	Hulands	AC 20 dense bin 40/60 des (2920C)	19.48	19.48	720	-1.667827	54.435001	36.3	184	08:30:35	
69049609	PN57OKX	Hulands	AC 20 dense bin 40/60 des (2920C)	19.52	39.00	813	-1.667452	54.433480	208	177	09:44:28	
69049812	CU05CWG	Hulands	AC 20 dense bin 40/60 des (2920C)	19.84	58.84	825	-1.666856	54.431079	401	167	10:50:11	
69049944	NU11ZXT	Hulands	AC 20 dense bin 40/60 des (2920C)	19.7	78.54	831	-1.666729	54.430567	431.1	168	10:58:03	
69050104	NX14UOE	Hulands	AC 20 dense bin 40/60 des (2920C)	20.1	98.64	839	-1.666515	54.4297104	496.7	171	11:21:06	
69050963	NX59BNN	Hulands	AC 20 dense bin 40/60 des (2920C)	19.16	117.80	927	-1.666399	54.4292493	513.9	178	11:27:13	
69051016	AE03UDW	Hulands	AC 20 dense bin 40/60 des (2920C)	19.86	137.66	931	-1.666178	54.4283613	530.8	182	11:37:34	
69051205	NX09DYD	Hulands	AC 20 dense bin 40/60 des (2920C)	19.5	157.16	943	-1.667854	54.434878	598.8	168	12:24:17	
69053562	SK06JRG	Hulands	AC 20 dense bin 40/60 des (2920C)	19.58	176.74	1208	-1.66743	54.4331706	755.5	164	13:09:38	
69053747	NX14UOE	Hulands	AC 20 dense bin 40/60 des (2920C)	19.38	196.12	1221	-1.667289	54.432603	787.2	168	13:38:02	
69054011	NX04LWD	Hulands	AC 20 dense bin 40/60 des (2920C)	19.76	215.88	1238	-1.667287	54.4325975	787.2	173	13:38:05	
69054162	NX06DVV	Hulands	AC 20 dense bin 40/60 des (2920C)	19.62	235.50	1251	-1.667213	54.4322997	817.6	178	13:48:27	
69054713	NX59BNN	Hulands	AC 20 dense bin 40/60 des (2920C)	19.44	254.94	1331	-1.666732	54.430330	964	166	14:49:20	
69053951	YJ55LUB		AC 20 dense bin 40/60 des (2920C)	10.12	265.06		-1.666634	54.429933	975.4	170	14:59:45	
69053575	N6NBT		AC 20 dense bin 40/60 des (2920C)	19.68	284.74		-1.666595	54.4297755	984.2	172	15:03:16	
69055733	NX14UOE	Hulands	AC 20 dense bin 40/60 des (2920C)	19.52	304.26	1442	-1.666306	54.4286216	1047.3	183	15:41:38	
69055954	NX04LWD	Hulands	AC 20 dense bin 40/60 des (2920C)	19.6	323.86	1500	-1.66796	54.4350687	1131.3	184	16:09:23	

Figure 26: Custom report

3.4 Results of contractors quality control

The contractor's usual regime for quality control on site was also followed on the day of the trial with examples of this shown in Figure 27 and Figure 28. These consist of a daily laying record and the record of the density gauge readings taken during the rolling process. These records are all filled in manually by a technician on site. It can be seen that when the records are compared to the MOBA system results that there are minor variations in chainages and temperatures which is down to the accuracy of the technician and averaging of the temperature readings he takes.

Northfleet, Kent DA11 9AX
Tel: 01474 333186
Fax: 01474 333581

TEMPERATURE LAYING RECORDS

Client	A1D2B	Date Laid	20/03/2015
Site	A1M Scotch Corner	Supplier	Aggregate Industries
Material	AC 20mm HDM 40/50	Source	Hullands
Location	A1 Northbound	Digital Ref	RNA DR001
		Probe Ref	RNA PR001
Reference		Tested By	R MUNTON

THIS TEST WAS CARRIED OUT IN ACCORDANCE WITH BS 598 PART 109, BS EN 12697-13, BS 594987 & ORGANOLEPTICALLY TO NHSS 16 Cl.7.4.3

Organoleptically Inspected #

Ch From	Ch To	Lane	Ticket (Source)	Time Loaded	Time Laid	Tons Del.	Tons Total	Average Delivery Temp ºC	Average Rolling Temp ºC	Inspected #	Remarks
0	35	1	69048681	07:20	08:30	19.48	19.48	180	150	YES	
35	210	1	69049609	08:13	09:45	19.52	39	176	152	YES	
210	400	1	69049812	08:25	10:50	19.84	58.84	161	148	YES	
400	430	1	69049944	08:31	11:00	19.7	78.54	162	149	YES	
430	500	1	69050104	08:39	11:20	20.1	98.64	168	151	YES	
500	515	1	69050963	09:27	11:27	19.16	117.8	170	155	YES	
515	530	1	69051016	09:31	11:37	19.86	137.66	160	147	YES	
530	595	1	69051205	09:43	12:24	19.5	157.16	158	145	YES	
595	705	1	69053562	12:08	13:09	19.58	176.74	162	145	YES	
705	755	1	69053747	12:21	13:38	19.38	196.12	170	149	YES	
755	785	1	69054011	12:38	13:38	19.76	215.88	174	152	YES	
785	815	1	69054162	12:51	13:48	19.62	235.5	178	153	YES	
815	960	1	69054713	13:31	14:49	19.44	254.94	161	150	YES	
960	975	1	69053951	13:52	14:59	10.12	265.06	165	149	YES	
975	990	1	69053575	14:01	15:03	19.68	284.74	172	151	YES	
990	1040	1	69055733	14:42	15:41	19.52	304.26	175	153	YES	
1040	1131	1	69055954	15:00	16:09	19.6	323.86	177	153	YES	

Authorised Signature: ________________________ Date:

Figure 27: Laying record

Foster Yeoman Contracting Ltd
Robins Wharf, Grove Road
Northfleet, Kent DA11 9AX
Tel: 01474 333186
Fax: 01474 333581

Insitu Density of Bituminous Material – Indirect Density Gauge

In House Procedure FYC WI 14h

Client	A1D2B		Date Laid	20/03/2015	Test Date	20/03/2015
Site	A1 Scotch Corner		Supplier	Aggregate Industries		
Material	AC 20 HDM		Source			
Location	A1		Theoretical Density kg/m³		2.555	*
Gauge Used	PQI 001	Offset	Tested By		R Munton	

DENSITY GAUGE RESULTS

Chainage	Nearside Beside Joint kg(m³)	Nearside Beside Joint Voids %	Nearside Wheeltrack kg(m³)	Nearside Wheeltrack Voids %	Centre Average kg(m³)	Centre Average Voids %	Offside Wheeltrack kg(m³)	Offside Wheeltrack Voids %	Offside Beside Joint kg(m³)	Offside Beside Joint Voids %	Remarks
50			2.455	3.9							
70							2.473	3.2			
90			2.460	3.7							
110							2.484	2.8			
130			2.479	3.0							
150							2.456	3.9			
170			2.466	3.5							
190							2.465	3.5			
210			2.470	3.3							
230							2.460	3.7			
250			2.490	2.5							
270							2.512	1.7			
290			2.440	4.5							
310							2.499	2.2			
330			2.465	3.5							
350							2.480	2.9			
370			2.500	2.2							
390							2.498	2.2			
410			2.438	4.6							
430							2.510	1.8			
450			2.429	4.9							
470							2.486	2.7			
490			2.410	5.7							
510							2.422	5.2			
530			2.430	4.9							
550							2.456	3.9			
570			2.439	4.5							
590							2.468	3.4			

*Notes: *Maximum Density Value to BS EN 12697 - 5: 2002 unless otherwise stated.*
Air voids calculated in accordance with BS EN 12697 - 8: 2003

Authorised Signature ______________________ Date ____________

Figure 28: Density readings

3.5 System outputs

The benefits of using the advanced equipment is that all of the information gathered can be interrogated and presented in a variety of ways depending on the target audience and their requirements. Figure 29 shows two such reports showing the delivered material temperature and the weather conditions over the period of the site trials. These are only very basic examples to give an insight into what is available. A major benefit for the client in the future will be the ability to go back and look at the records for a particular area of the contract and have access to all the data with respect to the material laid. This can be invaluable when some sort of failure occurs as an investigation can be undertaken to ascertain the reasons for that failure. Furthermore the information from other areas in the contract can be assessed to see if they are likely to fail in the near future to help plan any remedial works effectively rather than in a piecemeal fashion.

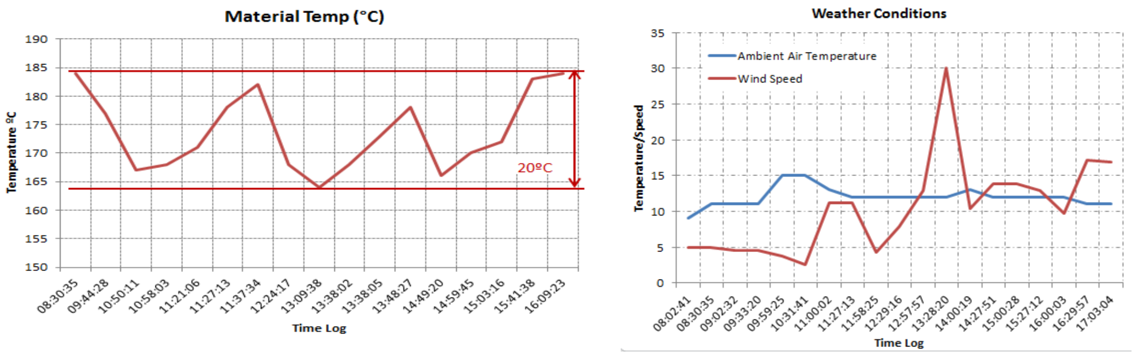


Figure 29: System outputs

3.6 Analysis of results

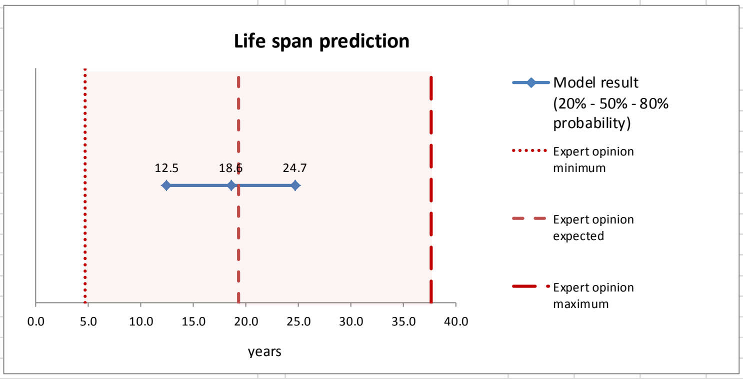
The Tool was used to calculate the anticipated design life for both before construction and after construction. The before construction information used was the typical values that would have been expected together with the typical site equipment that would normally be used in the UK. The after construction information used was that generated during the trial period.

The results for before construction are shown in Figure 30 and those for after construction are shown in Figure 31. These show that by adopting the limited methods available for this site that the anticipated life has increased from 18.6 to 19.6 years which represents a 5% increase in life. Although this may not seem to be a significant increase only a limited number of the quality control enhanced methods have been used and the costs of the implementation were low. This therefore shows a good return for the limited initial outlay and would indicate that if further measures were implemented then the extended life would be greater. The savings on extending the life of the surfacing by even 5% and a contract of this magnitude should be real interest to any client.

The small change in lifespan reflects that found in the Slovenian trial and would also suggest that further work is needed to fine tune the degradation factors and their effect in the Tool.

Tool for optimization of life span of asphalt

Model result		
mean predicted life span	18.6	years
minimum lifespan (20% lower boundary)	12.5	years
maximum lifespan (80% upper boundary)	24.7	years

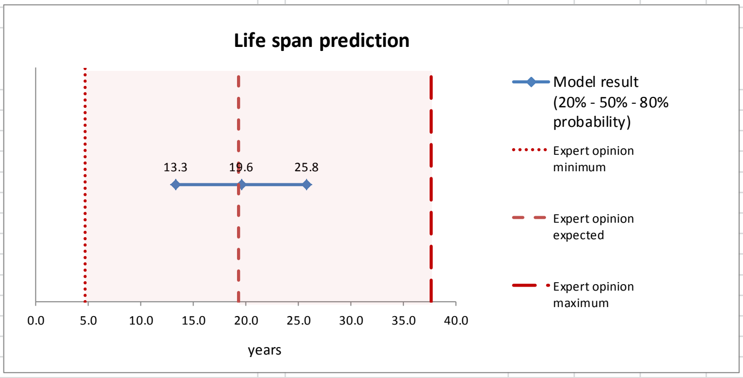


Model assumptions	
2.1 General	
Country:	England
This implies the model takes into account:	AC 20mm HDM
Length of section [m]:	20
This tool is used:	During contract phase

Figure 30 Tool before construction

Tool for optimization of life span of asphalt

Model result		
mean predicted life span	19.6	years
minimum lifespan (20% lower boundary)	13.3	years
maximum lifespan (80% upper boundary)	25.8	years



Model assumptions	
2.1 General	
Country:	England
This implies the model takes into account:	AC 20mm HDM
Length of section [m]:	20
This tool is used:	After construction

Figure 31 Tool after construction

4 Workshop

4.1 Introduction

Some issues regarding the input parameters of the model have arisen during the evaluation of the model results. Unfortunately the list of input parameters became quite extensive. Some of the input parameters have less influence on the change of pavement lifespan than others. During the building of the model it was realised that the input parameters of the model should be made more specific and weighting factors should be added to the input parameters/degradation factors. For example the experts consider the thermal segregation of asphalt during laying (difference in temperature and leading to difference in densities) to be an important factor for the life span of a road. Thermal segregation that can cause weak spots and it usually occurs during paver stops.

The overall objective of the workshop was to score the most important input parameters and to estimate weighting factors to the input parameters/degradation factors. In October 2015 a group of 19 experts from industry – contractors, asphalt producers, institutes (performing quality control testing) were gathered to discuss the tool, especially the input parameters to the tool that describe asphalt characteristics and process of transport, laying and compaction (TLC). In the beginning of the workshop the CONSISTEND project was presented as well as some of the results of the test field that was held in May 2015 on a motorway section near Celje.

Figure 32: Consistend workshop on 22nd October 2015 in Ljubljana

After a discussion a common agreement on the most likely lifespan expectancy for SMA11surf with polymer modified bitumen was reached. The majority of experts proposed 15 years for the expected pavement lifespan, 20 years for maximum and 10 years for the minimum, but not all experts agreed.

Figure 33: Consistend workshop on 22nd October 2015 in Ljubljana

Then questionnaires were distributed to all participants attending the workshop and the 19 experts filled them in. The answers were analysed and some conclusions are presented below. The aim of the questionnaires was to gather relevant information on the input parameters and their weighting factors for the specific asphalt mix that was used at the test site in Celje.

All 19 experts that were present at the workshop filled in the list of questions. In Figure 34 is shown the analyses of answers regarding the lifespan for SMA11surf with polymer modified bitumen (PmB 45/80-65). The analysis of the questionnaire showed an average expected lifespan (based on 19 answers) of 14.7 years for the expected pavement lifespan, 20.5 years for maximum and 8.1 years for the minimum pavement lifespan.
In the graphs are presented the minimum and maximum value (the thin vertical line). The bars (coloured rectangle) represent bandwidth (average+standard deviation to average−standard deviation).

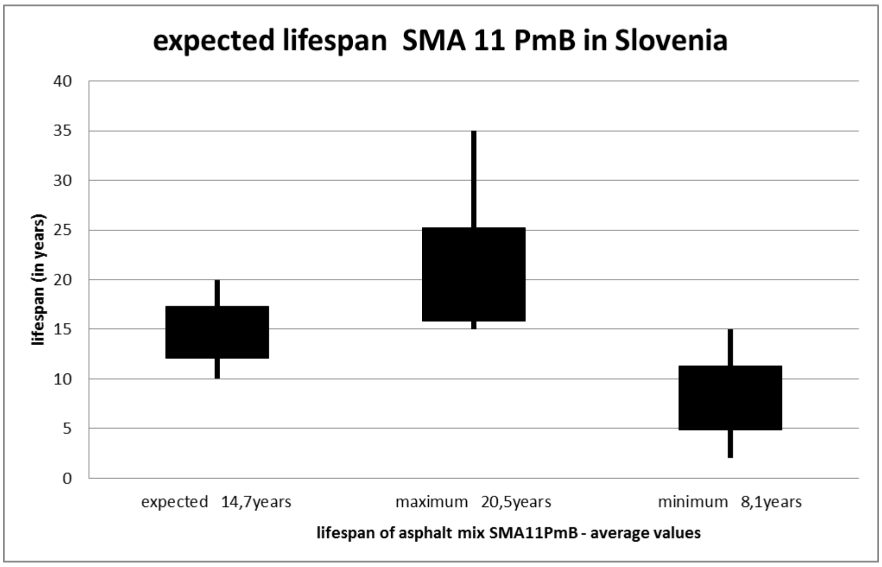


Figure 34: Estimated expected lifespan of SMA11surf PmB 45/80-65

4.2 Input parameters

During the development of the CONSISTEND tool the discussion showed that the number of input parameters/degradation factors that was initially taken into account was probably too extensive. From the list of 21 CONSISTEND tool input parameters, eleven input parameters were chosen. For the workshop feedback a list of eleven questions was prepared as shown in Figure 35. The aim was to seek for transparent relationships between the chosen input parameters and pavement lifespan. For these eleven parameters (numbered Q1 to Q11) the importance (weighting factors) of their influence on asphalt lifespan was also to be determined where possible.

The list of questions was put together taking into account Slovenian practice in paving that differs from practice in some other European countries. It should be noted that the answers cover a top layer asphalt mix taking into account climate conditions and national technical specifications etc. It should also be noted that the experts were well informed about the quality control (QC) of asphalt (tests on bitumens, asphalt samples, asphalt cores and compaction testing on site with nuclear method) but have little experience with innovative QC techniques - continuous asphalt IR temperature measurements, thermal segregation analyses, ALIS etc.

Questionnaires were distributed to all participants attending and the answers were gathered and analysed. The aim of the questionnaire was to gather relevant information for a specific asphalt mix - SMA11surf PmB 45/80-65 with a thickness of 4cm, as it was used in the test field in Celje in May 2015.

Four out of eleven input parameters that were addressed deal with asphalt characteristics that are usually tested within the scope of the usual QC programme.

- Q1. asphalt temperature during transport / at asphalt plant
- Q2. asphalt temperature during compaction
- Q3. void content
- Q4. compaction

Seven out of eleven input parameters deal with the asphalting works:

- Q5. experience of asphalt team
- Q6. thermal segregation - paver stops
- Q7. transport (more than 60min)
- Q8. transport time with insulated trucks
- Q9. equipment for paving
- Q10. equipment for compaction
- Q11. bonding

In questions numbered Q6 to Q10 presented in Figure 35 relationships were sought between pavement lifespan taking into account two cases of weather conditions - good weather conditions (temperature above 15^{o}C, no wind or rain) and bad weather conditions, (temperature below 15^{o}C, strong wind and/or rain).

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ZAG

Questionnaire influence of TLC on asphalt lifespan

SMA11 PmB45-80/65 (thickness 4cm, load class A2)

Answers from (constractor, engineer, control, producer)______________

experience ___________years

expected lifespan		years
max lifespan		years
min lifespan		years

question number	importance score 1 to 5	description of asphalt characteristics	in your opinion - **for how many YEARS the MAXIMUM lifespan of SMA11 is reduced?**			question number	
			too low T 160 C	*max permissible T is 190oC optimal = 175stC	too high T 200 C		
Q1		**asphalt T during transport / at plant**		0		Q1-1 -	Q1-1 -
			too low T 120 C	*min permissible T is 150stC optimal = 165stC	too high T 180 C		
Q2		**asphalt T during compaction**		0		Q2-1 -	Q2-1 -
			too low V/V <1,5%(V/V)	optimal V/V 4,5%(V/V)	too high V/V >7,5%(V/V)		
Q3		**void content**		0		Q3-1 -	Q3-1 -
			locally too low compaction 92%	*minimum 97% optimal 100%	locally too high compaction 103%		
Q4		**compaction**		0		Q4-1 -	Q4-1 -

	importance score 1 to 5	Description of asphalting works	in your opinion - **for how many YEARS the MAXIMUM lifespan of SMA11 is reduced?**				
			experienced	uncaring	inexperienced		
Q5		**experience of asphalt team**	0			Q5-1 -	Q5-2 -
			no wind, rain T>15stC good weather conditions		strong wind and/or rain in/ali T<15stC bad weather conditions		
Q6		**thermal segregation - paver stops**					
		paver stops from 5 to 15 min				Q6-1 -	Q6-1 -
		paver stops from 15 to 30 min				Q6-2 -	Q6-2 -
		paver stops from 30 to 60 min				Q6-3 -	Q6-3 -
		paver stopsmore than 60min				Q6-4 -	Q6-4 -
Q7		**transport (more than 60min)**	good weather conditions		bad weather conditions		
		covered trucks				Q7-1 -	Q7-1 -
		insulated trucks				Q7-2 -	Q7-2 -
		heated trucks	0			Q7-3 -	Q7-3 -
Q8		**transport time with insulated trucks**	good weather conditions		bad weather conditions		
		60 minuts	0			Q8-1 -	Q8-1 -
		120 minuts				Q8-2 -	Q8-2 -
Q9		**equipment for paving**	good weather conditions		bad weather conditions		
		paver				Q9-1 -	Q9-1 -
		paver + shiuttle buggy				Q9-2 -	Q9-2 -
		paver+GPS and Temp measurements				Q9-3 -	Q9-3 -
		paver+shuttle buggy +GPS and Temp measuren	0			Q9-4 -	Q9-4 -
Q10		**equipment for compaction**	good weather conditions		bad weather conditions		
		rollers				Q10-1 -	Q10-1 -
		rollers with GPS and Temp measurements	0			Q10-2 -	Q10-2 -
			Unclean surface	inconsistend rate of bond coat	cleans surface, homogenous rate of bond coat		
Q11		**bonding**			0	Q11-1 -	Q11-2 -

Figure 35: Consistend workshop in Ljubljana – questionnaire

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4.3 Weighting factors of input parameters

For each of the eleven input parameters/degradation factors the experts were asked about the importance of the parameter for the lifespan of the pavement. They were asked to score them from 1 (low importance) to 5 (high importance) to obtain weighing factors. The results are presented in Figure 36. It can be concluded that their opinions differ significantly and are not consistent. Five input parameters were scored from 1 to 5 (all possibilities), six of them from 2 to 5. In the graphs in Figure 36 are presented the minimum and maximum value of weighting factor (the thin vertical line). The bars (coloured rectangles) represent bandwidth (average+standard deviation to average−standard deviation) for each question. In the X axis are described the question number the average weighting factor and actual question.

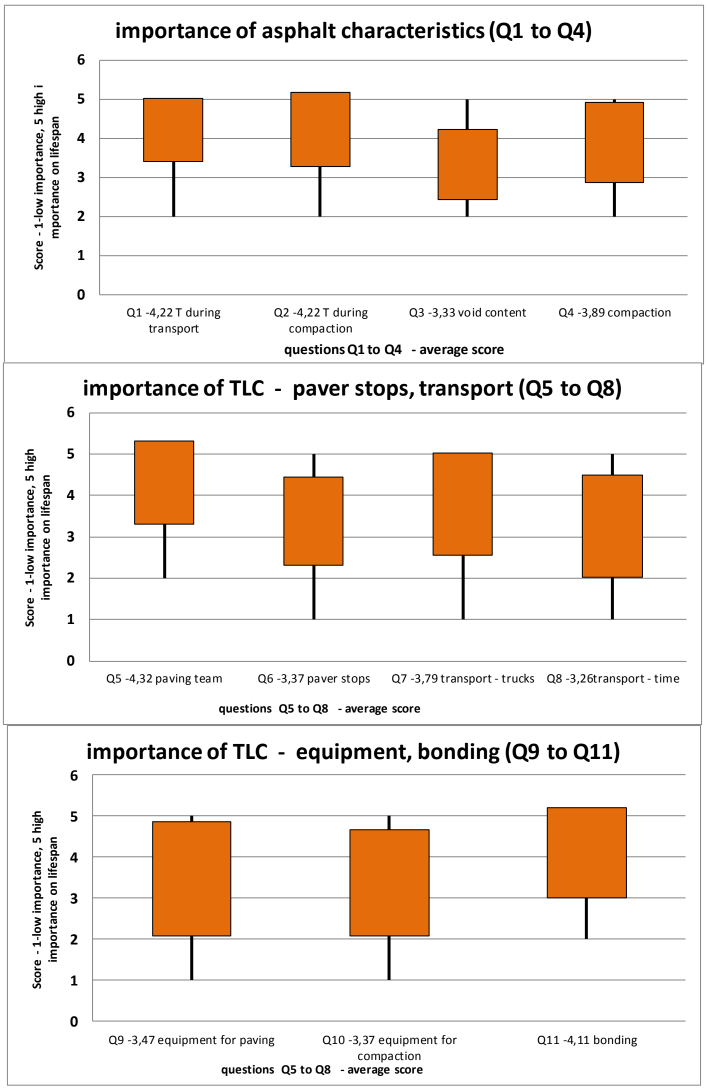

Figure 36: Importance – weighing factors

Experts agreed that asphalt temperature during transport (Q1) and compaction (Q2) are very important. Compaction (Q4) in relation to maximum density is more important than void ratio (Q3) for SMA11. The competence of the paving team (Q5) is most important, as expected. A trained paving team does not allow for paver stops and other deficiencies during paving (evenness etc.). According to their opinion thermal protection of asphalt during transport (Q7) is more important than the total delivery time (Q8). Transport time (Q8), equipment for paving (Q9) and compaction (Q10) are considered less important factors. Such answers were expected since the contractors, competing for contracts on highly trafficked roads need to prove in the pre-qualification process the availability of technically suitable equipment. The transport times are usually not longer than 90 minutes. From the results it can be concluded that expertise of paving team, temperature during compaction/transport and bonding are the most important input parameters/degradation factors. Void content, paver stops and transport time seems to be least important input parameters from the list of 11 parameters.

For establishing reliable weighting factors for the tool’s input parameter a much more specific questionnaire should be prepared.

4.4 Estimation of lifespan

In the graphs in Figure 37 to Figure 41 are presented the minimum and maximum value of lifespan reduction (the thin vertical line) in comparison to the maximum estimated lifespan. The bars (coloured rectangles) represent the bandwidth (average+standard deviation to average−standard deviation) for each question. On the X axis are described the question number, the average lifespan reduction (in years) and actual question text.

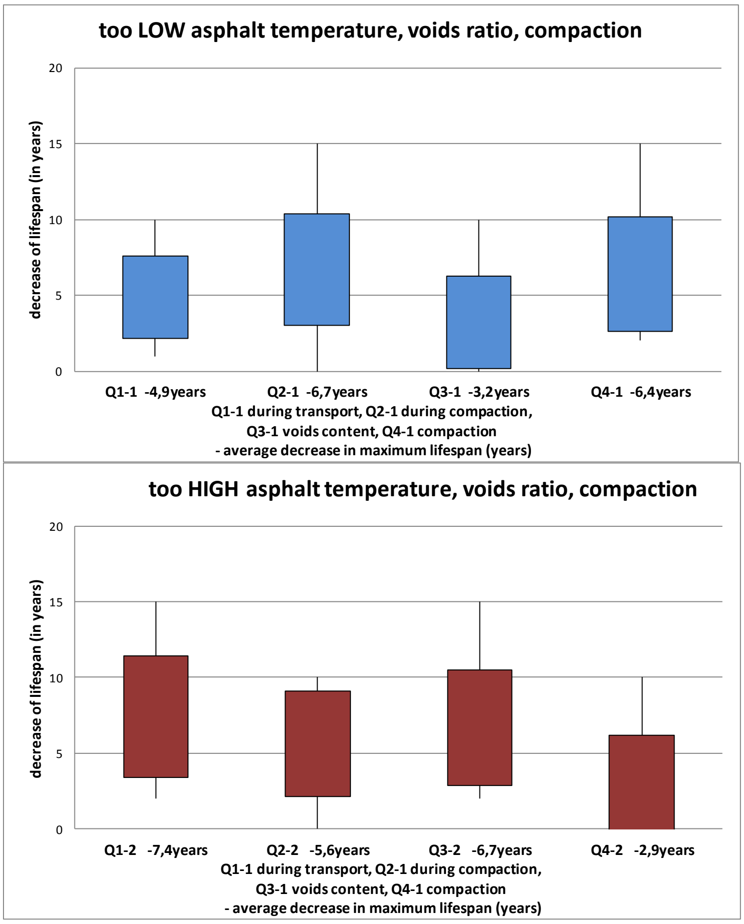

Figure 37: Temperature, void ratio and compaction

From Figure 37 it can be concluded that excessively high temperature of asphalt (above the temperature recommended by the binder producer) during asphalt production or transport has an adverse effect on pavement lifespan. Actual temperature of asphalt during compaction that is lower than recommended by the binder producer for compaction also has an adverse effect on lifespan. According to experts' estimations excessively high void content due to poor compaction also has a significant influence on asphalt lifespan.

We looked for a relationship between pavement lifespan taking into account two cases of weather conditions - good weather conditions (temperature above 15^{o}C, no wind or rain) and bad weather conditions, (temperature below 15^{o}C, strong wind and/or rain).

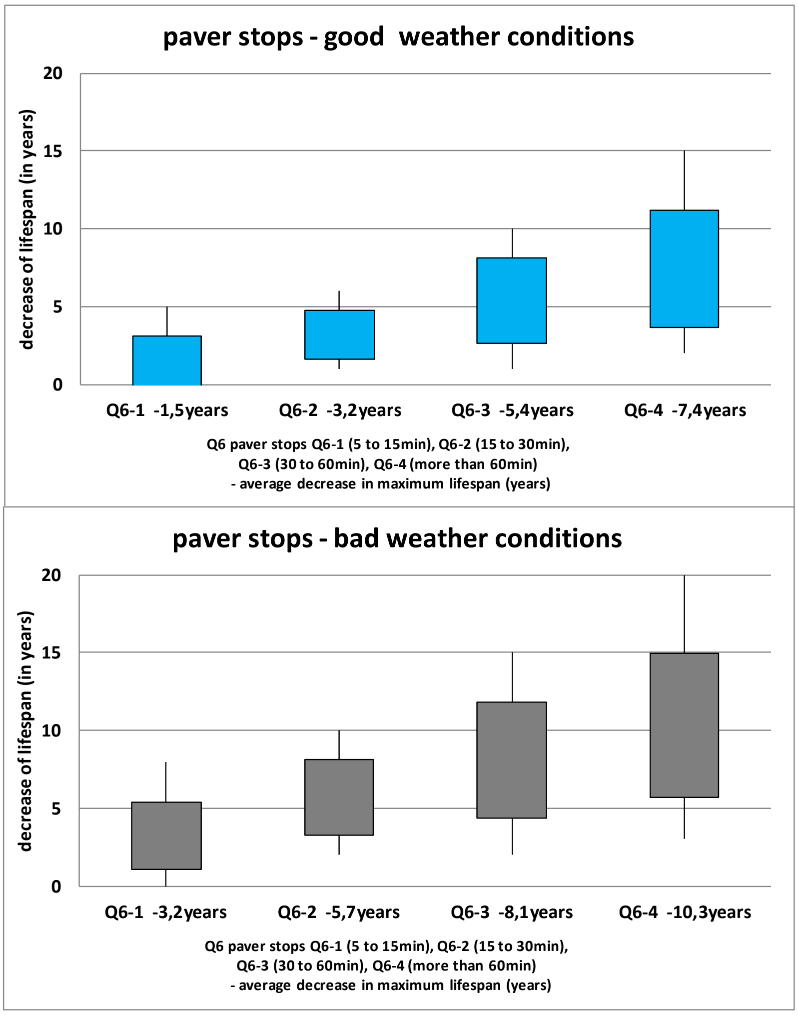

Figure 38: Paver stops

According to the experts' opinions paver stops in cold, windy weather have the most harmful effect on pavement lifespan (see Figure 38). Long paver stops (longer than 30 minutes) that enable significant cooling of asphalt before beginning of compaction may reduce the lifespan by more than 10 years.

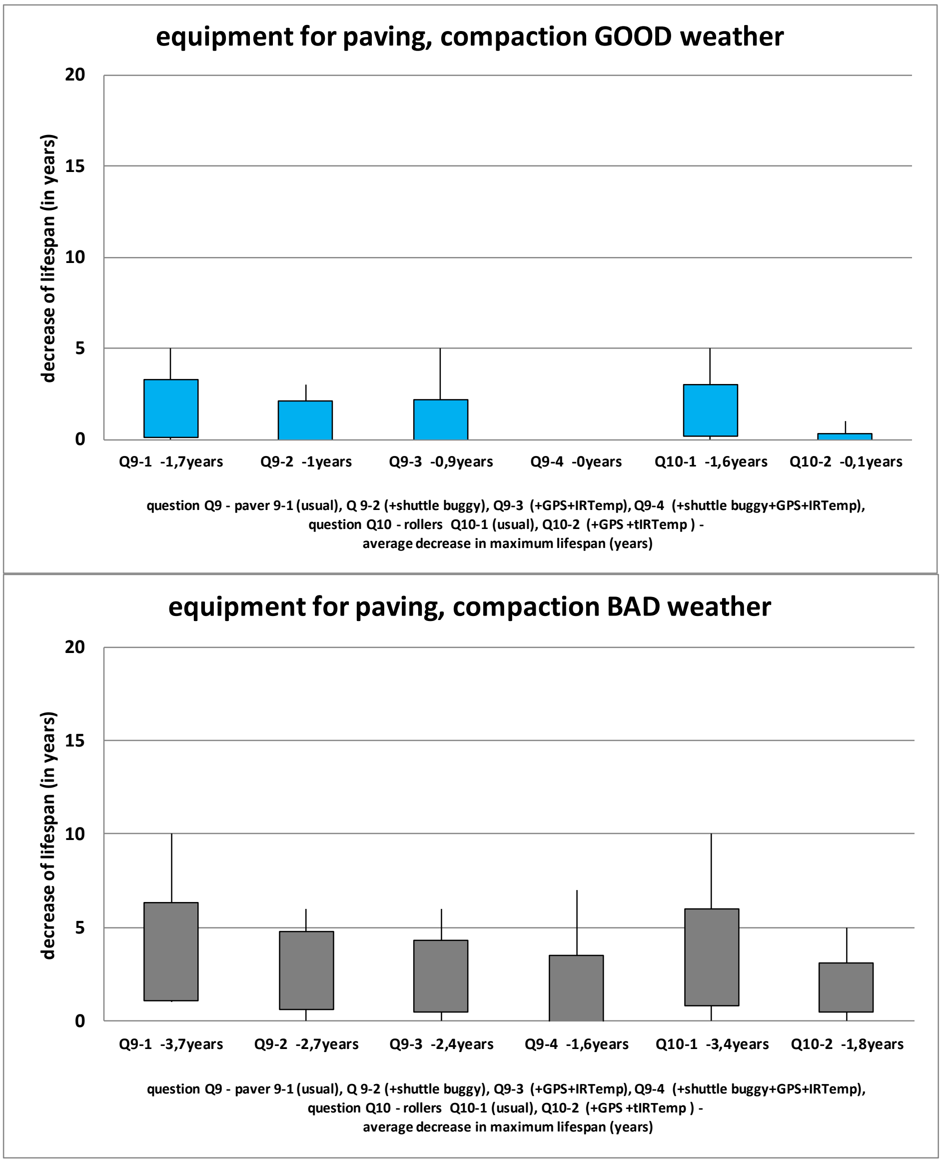

Figure 39: Equipment

Form Figure 39 it can be concluded that equipment for paving does not have a significant influence on pavement lifespan in good weather conditions. Assuming that the use of paver +shuttle buggy + IR temperature profile scanning) have a zero (0) effect on lifespan, it is estimated that when using a conventional paver (without the shuttle buggy and IR temperature profile scanning) the lifespan reduction is -3,7years on average.

According to the results of the questionnaire, transport in good weather conditions does not have a significant influence on asphalt lifespan Figure 40. In cold and windy weather transport in trucks without thermal insulation and transport longer than 120 minutes must be avoided.

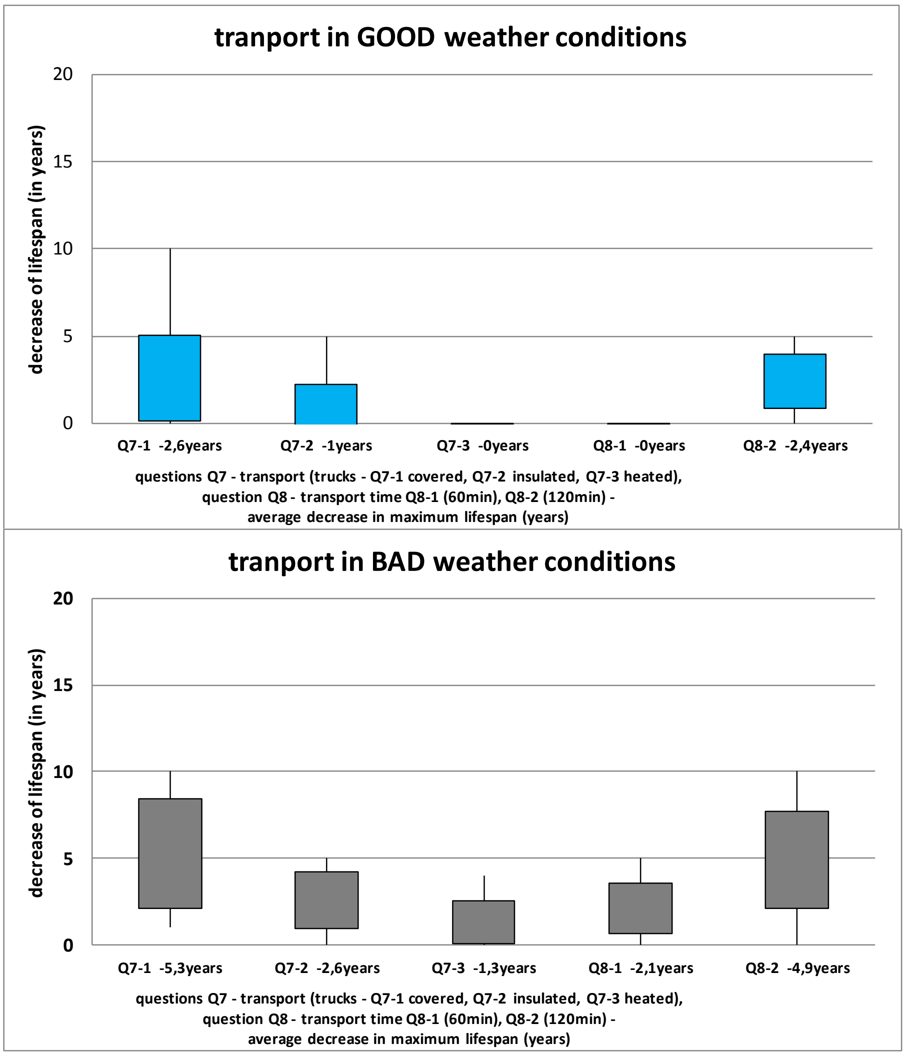

Figure 40: Transport

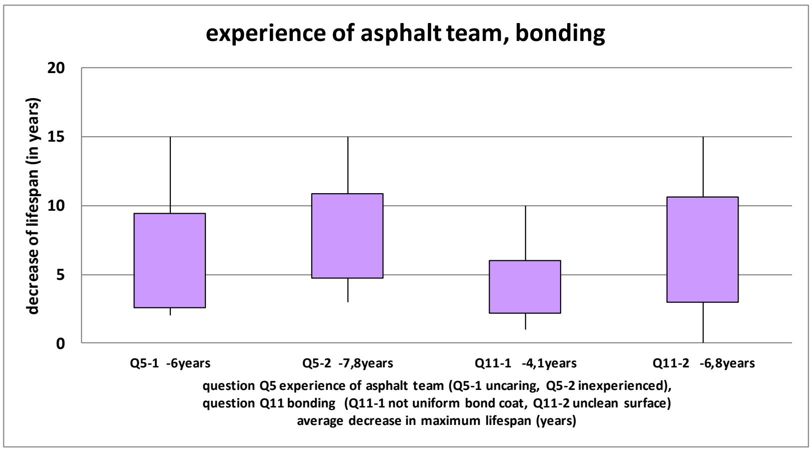

Figure 41: Experience of asphalt team, bonding

From the results of the questionnaire it can be concluded that the highest damaging effect (reduction of maximum lifespan for more than six years for SMA11surf PmB 45/80-65) occurs in the following situations:

- too low asphalt temperature during compaction,
- too low compaction
- too high void content,
- too high temperature of asphalt at transport/asphalt plant (higher then recommended by the binder producer),
- paver stops longer than 30 minutes in bad weather conditions,
- paver stops longer than 60 minutes in good weather conditions,
- unclean surface of bottom layer (no bonding)
- inexperienced asphalting team.

From the answers it can be concluded that there is a severe damaging effect (reduction of maximum lifespan for four to six years) when there is:

- too high temperature at paving/compaction,
- too low temperature at transport,
- paver stops of more than 30 minutes in good weather conditions,
- paver stops of more than 15 minutes in bad weather conditions,
- truck with no thermal insulation in bad weather conditions,
- transport time of more than 120 minutes in bad weather conditions¸
- inconsistent rate of bond coat,
- uncaring asphalt paving team.

Asphalt mix basically consists of time stable inorganic aggregates and rheologically very demanding thermo-viscoelastic bitumens, whose characteristics are also time dependent. The construction of a model that could take into account all the quality parameters of bituminous mixtures is not feasible. The tool evaluates only the process of transport, laying and compaction (TLC). Segregation of the asphalt material during transport and the appropriate temperature of the asphalt mixture are crucial factors which affect the TLC process.

During laying and compaction numerous actions may trigger thermal segregation or other weaknesses and thus shorten the lifespan of the asphalt. The results of the questionnaire also showed that the Transport Laying and Compaction process is very demanding and actions are inter-dependent. The eleven evaluated parameters have large influence on the pavement lifespan and are also inter-dependent.

For some construction parameters, research results have already defined some inter-dependencies (e.g. the optimum compaction temperature of bituminous mixtures). However, clear and straightforward inter-dependencies of the parameters, measureable with advanced quality control methods during the TLC process (weather conditions, paver stops, etc.), on the absolute increase or reduction of pavement lifespan are not yet available.

For establishing expert opinion on relationships of tool's input parameter measureable with advanced quality control methods during the TLC process (weather conditions, paver stops, etc.), on the absolute increase or reduction of pavement lifespan a much more specific questionnaire should be prepared and a much larger group of experts should be involved in the analysis.

5 Conclusions

The service life of a pavement surface courses is highly dependent on the construction process. A large number of parameters have to be controlled and kept at optimum during the transport, laying and compaction process. The temperature of the asphalt mixture during laying and compaction process (roller passes) have the most important effect on the uniformity of the degree of compaction and the evenness of the asphalt layer. Segregation and cooling of the asphalt mixture during transport reduces the life span of a pavement.

The construction of a model that could take into account all the quality parameters of bituminous mixtures is not feasible. The tool evaluates only the process of transport, laying and compaction (TLC) during which numerous actions may trigger thermal segregation or other weaknesses and thus shorten the lifespan of the asphalt. In the CONSISTEND model the results of the tool are based on purely empirical ‘expert opinion’ regarding the influence of TLC on pavement lifespan.

The results of the two pilot studies showed that the application of advanced quality control techniques during construction can provide a much more detailed and more reliable insight into the quality of the actual transport, laying and compaction process, and thus into its influence on the pavement lifespan prediction. However, this quality control technique cannot provide measured results for all the input parameters of the tool.

The ‘real case’ project in Slovenia completed in 2015 identified in detail the benefits of innovative techniques for control of pavement works. The tested devices for IR scanning of thermal profile also allowed for measuring and recording of weather conditions and paver speed. However, it was established that this quality control technique cannot provide measured results for all of the input parameters of the tool.

In order to demonstrate the applicability of the proposed tool, it was decided to compare the lifespan prediction for the ‘during contract phase’ with that for the ‘after construction phase 1’ taking into account the results of usual scope of quality control and that for the ‘after construction phase 2’ taking into account the results obtained by of implemented thermal profile scanning.

Results of lifespan prediction with the tool demonstrate that the mean value of the predicted lifespan lies between the minimum and maximum lifespan, as expected. However, the calculated lifespan for ‘during contract phase’ is somewhat shorter than expected, since good paving conditions, experienced team and no harmful deviations were considered.

Results of lifespan prediction for ‘after construction phase 1’ with the tool demonstrate that the mean value of the predicted lifespan is shorter than for ‘during contract phase’. Results of lifespan prediction for ‘after construction phase 2’, with the tool demonstrate that the mean value of the predicted lifespan is shorter than for ‘after construction phase 1’. This was anticipated since the innovative technique provided some of the parameters were more unfavourable. However, the change in mean value of the lifespan prediction is relatively small, and smaller than expected by the experts in the CONSISTEND project team.

The relatively limited response of the model to change in project values of the input parameters can be explained by the summation of the influence of the degradation factors in the model, in combination with the high number (twenty one) of input parameters. To increase the response of the model to a change in values of the input parameters, significantly less input parameters should be defined in a next version of the tool. It is proposed that weighting factors to individual input parameters be introduced.

For some construction parameters, research results have already defined some inter-dependencies (e.g. the optimum compaction temperature of bituminous mixtures). However, clear and straightforward inter-dependencies of the parameters, measureable with advanced quality control methods during the TLC process (weather conditions, paver stops, etc.), on the absolute increase or reduction of pavement lifespan are not yet available.

Further research is needed in order to be able to calibrate the model and quantify the absolute change in service life taking into account countries' specific technological practices, bituminous mixtures types, and climatic conditions. Optimisation of the model regarding a reduction in the number and weighting of the most relevant project dependent variables is also needed.

Contractors and road managers understand the benefits of new quality control techniques employed during transport, laying and compaction process. It is however not yet possible to objectively weigh the costs of these techniques against the value.

6 References

http://moba-automation.com/machine-applications/asphalt-pavers/pave-ir-scan/ (accessed 20 February2016)