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

WP1-Report 1.1b: Industry Feedback

Milestone 1.3
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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

WP1 – Report 1.1b: Industry Feedback

Due date of milestone: 31/03/2015

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

D1.1: Final report summarizing the findings of the reviews after quality check.

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Executive summary

On completion of the literature review it is clear that there are many factors and mechanisms which can influence the quality and durability of a pavement. It should be acknowledged that many of the factors are interdependent and prove difficult to assess on an individual basis. However, following review of the numerous pavement functions, degradation mechanisms and factors it has been possible to develop a relation matrix to conclude report 1.1a. This matrix will assist with the development of the model and provide the main focus for the industry questionnaire which is reported in this document.

Following consultation with industry it is clear that the parameters identified in this study have an effect on lifespan of materials. It is also apparent that some of those parameters are difficult to quantify in relation to life and many remain inextricably linked. From the industry questionnaires reviewed it is clear that despite the country or material many of the parameters effecting quality are the same and measures such as adhering to temperatures, use of intelligent equipment, increase in bond coat and number of roller passes are all viewed as having a positive contribution to increasing life.

Further analysis of the results of this study will be reported in WP2.

1 Introduction

Quality control during the construction process is, next to road design and material selection, an important factor that determines the performance of an asphalt road with respect to service life. A longer functional life of a road has an enormous impact on the carbon footprint of that road because it minimizes the use of materials and energy during the life cycle. The road construction sector faces a number of changes that have an impact on quality control.

Firstly, under the impact of new types of contracts like Design, Build, Finance and Maintain (DBFM), the responsibility for quality control moves from road owner to contractors. These types of contracts have changed the quality control from a check made by the client to ensure work was realized according to specifications, to a quality system installed by a contractor to minimize financial risks during the project. As a result of this different prospective, investment in advanced techniques for quality control have now become rewarding for contractors.

Secondly, the workforce of construction companies is changing more rapidly, people change jobs, companies are taken over, etc. Subsequently road construction teams are subjected to frequent changes, which reduce the total knowledge of the team and the transfer of this knowledge. As the construction quality of asphalt roads is largely dependent on the empirical experience of the construction workers, this lack of continuity has a negative effect on the service life and performance of a road.

Finally, there are new technologies that have become available over the past decades that can take quality control to a whole new level. With the help of these technologies a wide selection of parameters can now be monitored during construction in real time. For example with the use of infrared sensors the temperature of the whole asphalt surface can be monitored, for example, just after the screed; through GPS the number of roller passes can be monitored at each location; and the foreman can obtain accurate information about the location and expected arrival time of asphalt trucks, the possibilities are endless.

If quality control is brought to the next level it is possible to create a population of roads with a longer and much more predictable average service life. However, at this time an important challenge is the limited knowledge available on the influence of the individual construction parameters on the service life of pavements, which makes it difficult to quantify the absolute gain in service life. If it is possible to quantify the additional service life obtained by installing quality control methods, this will not only be an incentive for contractors to use these methods, but also assist with the planning and management of future maintenance interventions. Additionally, when the influence of the individual construction parameters on the service life of pavements is known, quality control can be focussed on controlling these parameters.

The next step is to quantify the impact of the use of advanced quality control methods on the average and standard deviation of the relevant service life parameters. When this information is combined it is possible to design a quality control system that is able to realise the required risk level for a specific project.

The project will start with the collection of information on the influence of the construction process on the service life of asphalt roads. This information is gathered within this document and forms the basis for deliverable 1.1.
This report covers the following key points;

- comprehensive review of literature related to the asphalt pavement construction process,
- the key construction parameters that determine service life performance,
- how they will influence performance for different types of asphalt layers under different climate conditions.

2 Definitions and abbreviations

For the purposes of this report European Standards apply, as do the following terms and definitions [Read, 2003 and BSI, 2006]

Pavement, structure, composed of one or more courses, to assist the passage of traffic over terrain

Layer, element of a pavement laid in a single operation

Course, structural element of a pavement constructed with a single material. A course may be laid in one or more layers

Surface course, upper course of the pavement, which is in contact with the traffic

Binder course, part of the pavement between the surface course and the base

Regulating course, course of variable thickness applied to an existing course or surface to provide the necessary profile for a further course of consistent thickness

Base, main structural element of a pavement. The base may be laid in one or more courses, described as “upper” base, “lower” base etc.

Asphalt Concrete, asphalt in which the aggregate particles are continuously graded or gap-graded to form an interlocking structure

Tack coat (or bond coat), light application of bitumen applied between layers of asphalt to create a strong adhesive bond.

Fretting (or ravelling), the progressive loss of interstitial fines from the road surface.

Stripping, the loss of bond between the aggregates and bitumen, resulting in loose material.

Rutting (or deformation), permanent or unrecoverable traffic-associated plastic deformation often restricted to surface layers, can extend throughout the pavement.

Bleeding (or fatting up), occurs when binder fills the aggregate voids resulting in excess binder on the surface

Cracking, occurs when tensile stress and related strain induced by traffic and/or temperature changes exceeds the breaking strength of the mixture.

3 Improving Quality

From the review and industry feedback performed in this Work package, it is possible to identify the various parameters and quantify the influence they have on the service life.

Included in the questionnaire are parameters which are believed by the authors to assist in improving quality such as the use of technology during paying and laying. This section of the report aims to look at other instances where this has been used and introduce the types of technology available. The data gathered from the questionnaire and reviews will be used in the CONSISTEND tool, which will be developed and reported on through WP2 of this project.

3.1 Best practice

In combination with the myriad of factors that can affect the paving process there is increasing pressure to construct pavements in less than ideal conditions which results in the desired quality and performance of a pavement being under threat. This makes it important for decision makers and contractors to gain insight into the factors that cause degradation and the extent to which they are of influence on the service life of the pavement. When the governing factors that cause degradation of the pavement are known, the use of quality control methods can focus on (locally) altering the non-ideal conditions that are of influence on these factors.

Previous research has been conducted in this field. This project draws on the experience and work of this previous research. For example, this project builds on Lifetime Optimisation Tool (LOT) work which stimulated product innovation, optimised production process and assists learning with the ultimate goal of extending the life time of porous asphalt with respect to ravelling and covering the whole design and construction process. The LOT allows input of construction parameters that allow any changes made to the construction process to feed into the program which results in a new service life prediction (de Rooij, 2007). Much like the CONSISTEND project the model combined measured data in literature with expert judgement however it also includes a physical model on the cooling of asphalt. In both projects uncertainties are made explicit. Insight in uncertainties in service life predictions are extremely useful for decision makers and makes it possible for contractors to decide which parameters they want to look at when they are using quality control methods. From the review and industry feedback performed in this Work package, it is possible to identify the various parameters and quantify the influence they have on the service life. The gathered data will be used in the CONSISTEND tool, which will be developed and reported on through WP2 of this project.

Another example of research in this field, that also aims to professionalise the paving process, is the cooperative network, calls ASPAri (short for ASphalt PAving, Research and innovation), created by the University of Twente and 11 Dutch contractors . Within this network, GPS-technology, a laser line scanner and infrared cameras are used to provide insight in the paving process. This data can be transferred to graphs and animations and the results are used to give feedback to asphalt teams. The intention is to reduce variability in working methods and results, improve process quality and reduce the risk. Using the ASPARi-equipment (GPS, laser line scanner, thermocouples and infrared cameras), it is possible to register the lay-down temperature, the cooling rate, the number of roller passes, the temperature at certain roller passes, etc. for the entire paved road. However, the measured data and its relationship with the mechanical and the functional quality will not be directly clear. Hence, the ASPARi-approach as yet does not determine the effects of different compaction temperatures on the final density and quality of the pavement. It is however, important to work towards a more method-based process, which will make it possible to reach the desired quality, despite working under less than ideal circumstances. These methods and procedures can then be a starting point to become a 'learning organization' (Bijleveld, 2012).

Through discussion with Frank Bijleveld it is understood that the ASPARi project does not make any relationship with lifespan (which is the main difference with the Consistend project) and is focused on registering parameters during construction, and how it can be used to predict temperature differences in the pavement and adapt the construction processes on the temperature. Whilst the ASPARi project is focused on how to monitor several construction parameters, it is not yet related to the (final) quality in time. It should be noted that one of the more difficult aspects of such a project is that often operatives are not used to new ways of working and registering all of the data required, further implementation hurdles include the sometimes prohibitive cost of equipment required to undertake such work.

3.2 Intelligent Equipment

With increasing advances in technology, industry is continually looking for ways to improve. The introduction of 'intelligent' equipment is allowing technology to penetrate the asphalt pavement sector, more specifically intelligent compaction (IC) to assist in its quest to improve quality. Using modern vibratory rollers equipped with an in-situ measurement system and feedback control, Global Positioning System (GPS) based mapping, as well as software that automates documentation of the results IC rollers are beginning to increase in frequency of use. By integrating measurement, documentation, and control systems, the IC rollers allow for real-time monitoring and correction of the compaction process. IC rollers also maintain a continuous record of (nominally) colour-coded plots that indicate the number of roller passes, roller-generated material stiffness measurements, and precise location of the roller. Furthermore Chang et al, 2011 report that the precise location of the roller, speed, and number of passes over a given location are also mapped using GPS. These systems are commonly used to establish grade and to control other pieces of equipment. Compaction meters or accelerometers are mounted in or about the drum to monitor applied compaction effort, frequency, and response from the material being compacted. The readings from this instrumentation determine the effectiveness of the compaction process. The methodology to calculate material response to compaction is often proprietary, resulting in various types of intelligent compaction measurement values (ICMV). In addition, asphalt IC rollers, temperature instrumentation is added and used to monitor the surface temperature of the asphalt pavement material. As discussed in report 1.1a, this is critical as vibratory compaction within certain temperature ranges can have adverse effects. Overall the technology is in place and available for use to monitor many of the parameters discussed in this report which are not always easy or required to be captured, yet can have a significant impact on quality of the finished pavement material.
Benefits of IC technology are believed (Chang et al, 2011) to be;

- IC mapping of existing support layers is effective in identifying weak support areas for corrective actions prior to the compaction of the upper layers.
- With hot mix asphalt IC, tracking roller passes and surface temperatures provide necessary means to maintain a consistent rolling pattern within optimal ranges of temperatures for 100 percent coverage of a construction area.
- IC technologies can be especially beneficial to maintain consistent rolling patterns under lower visibility conditions such as night paving operations.
- IC technology will have profound influence on the responsibilities of various stages of pavement constructions and will eventually help produce better and more consistent pavement products.

Pavement trials incorporating this technology are on-going and taking place throughout the world. Chang et al, 2011 report on 16 field trials across the US for the development of intelligent compaction specifications. Whilst technology evolve reports available to date aim to disseminate knowledge and accelerate implementation of technology, however, technology will take time to be accepted and as correlations between intelligent measurement and long term performance continue to be developed.

Work elsewhere, (Doree et al, 2012), has also shown that there are several technology pitfalls to be aware of. Acquiring new technologies (GPS, laser line scanners) does not mean that it can be integrated directly into work processes. Confirming that it takes time to test, set up and calibrate and ensure that data transfer mechanisms work and personnel become used to the technology. These are lessons for contractors wanting to adopt the Process Quality Improvement (PQi) methodology, investment in these new technologies and wanting to monitor their own hot mix asphalt construction processes in the future. For the contractors, the information gathered (graphs, visuals and animations) proved to be a useful window to view the process and provided a useful tool for the paving gang to reflect on their construction work. Overall, monitoring process parameters is seen to have several advantages, for contractors as well as road agencies, including that key process parameters are kept in control leading to a more consistent product, and that the data-rich environment means that both contractor and road agency are able to use permanently geo-referenced data for the future monitoring of pavement distress and premature failure.

Further detail and overview of current technologies will be reported in WP3 of this project.

4 Industry Feedback

The impetus for the use of statistical methods in managing highway construction quality began in 1963 with an initiative led by the Bureau of Public Roads Washington. Techniques originally developed in the 1930s and 1940s for the manufacturing sector was applied to the problem of controlling highway materials quality. A few pioneer state departments of transportation followed the federal lead and applied statistical quality-level analysis (QLA) to their projects. Many states are now adopting these procedures after seeing them used successfully for nearly 30 years. Given this renewed interest in and the important role that statistical estimates are now playing in materials quality assurance, it is fitting to re-examine the appropriateness and underlying assumptions of QLA (Benson et al, 2000).

Production line manufacturing processes, with their small, random fluctuations in output quality, are particularly well suited to this model. Construction output quality, on the other hand, is influenced by many semi controlled or uncontrolled factors and therefore can be expected to produce larger and possibly more irregular variations in output. Since work is extended over weeks or even over months or years, systematic changes in critical factors (e.g., weather, aggregate source, equipment, and personnel) can substantially influence the distribution of test results (Benson et al, 2000).

On completion of the literature review it became clear that there are many factors and mechanisms which can influence the quality and durability of a pavement. It should be acknowledged that many of the factors are interdependent and prove difficult to assess on an individual basis. However, following review of the numerous pavement functions, degradation mechanisms and factors it was possible to develop a relation matrix in report 1.1a. This matrix will also assist with the development of the model and provided the main focus for the industry questionnaire. A copy of the relation matrix is supplied separately in a pdf file to be attached in Appendix A. The matrix brings together the information and displays the main function of the pavement at the top of the chart; the colour coding defines whether the function relates to safety, performance or service. Degradation mechanisms and factors form the basis for the matrix and are displayed horizontally and vertically respectively. To broadly link the mechanisms to the degradation factors an 'X' is marked in the correct column. To further define the degradation factors during the phases considered in this project the factors are split into T = transport, L = laying and C = compaction and assigned the following in accordance to the perceived likelihood of the mechanism occurring, H = high, M = medium and L = Low.

To supplement the literature review and build on the relation matrix developed, the project aims to seek the views of experts from within the asphalt industry, equipment manufacturers and NRA's and it is expected that knowledge gaps will be prevalent if fully reliant on literature.

4.1 Industry Questionnaire

To supplement the literature review, the project will seek the views of experts from within the asphalt industry in the form of a questionnaire. The objectives of the questionnaire were to;

- Target any gaps in the information obtained
- Quantify the expected, minimum and maximum service life of an asphalt road constructed from a (county specific) type of asphalt.
- Quantify optimal, minimum and maximum values for the degradation factors;
- Quantify change in service life when changing the degradation factor from optimal to minimum or from optimal to maximum

A copy of the questionnaire is supplied separately to be attached to Appendix B, the results of which are can be found summarised below for the various countries.

All summarised responses are shown as a normal distribution curve show three ± standard deviations from the mean (y axis). Where there is no known effect (i.e. standard deviation of zero) data lines are missing, workmanship has not been reported in detail as this has proven difficult to quantify as noted through conversations with colleagues and peer group. Whilst no known effect is equal to zero, parameters proving difficult to quantify such as workmanship are taken to be unquantifiable rather than no effect. However, results for all countries can be found summarised in Appendix C.

4.1.1 England and Ireland

As documented in report 1.1a, the most popular surfacing material in England and Ireland was HRA 35/14 F Surf 40/60, as such this was the material chosen as the focus of the questionnaire responses. In total 14 responses from across industry were obtained at the time of writing and included consultants, contractors, local authority and National Road Authority Engineers, providing a broad spectrum of expertise. It is clear to see that from Figure 1 that both expected life and minimum lifespan expected from the material have a consistent view from industry. The maximum lifespan however is more varied by response.

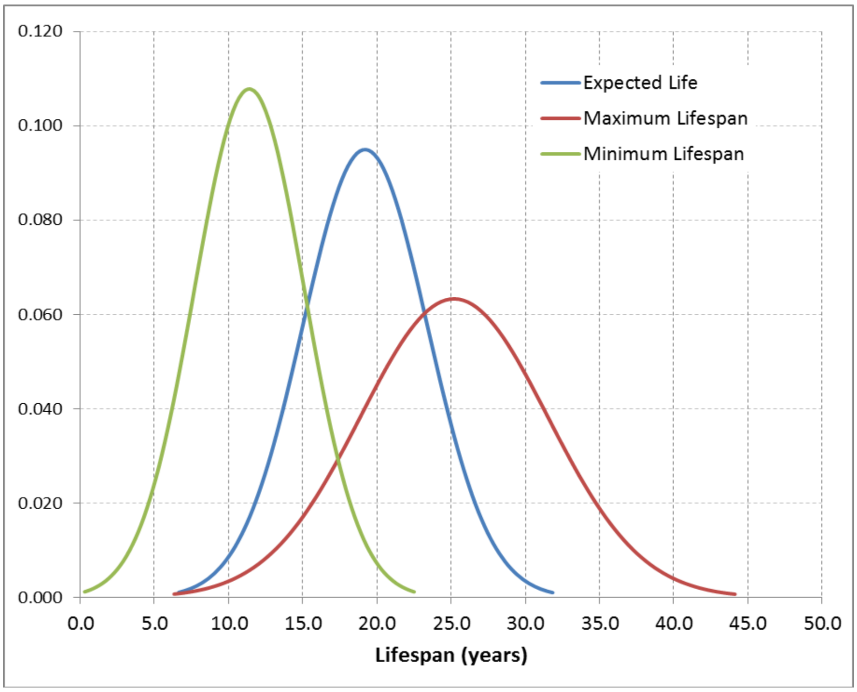

Figure 1**:** HRA 35/14 F Surf 40/60 material lifespan responses.

Figure 2 shows mixed view from industry with regards to material temperature during transportation as demonstrated by the flattened nature of the distribution curve. Material temperature during laying and compaction show a consistent response from industry with results indicating that these aspects can have an effect on lifespan.

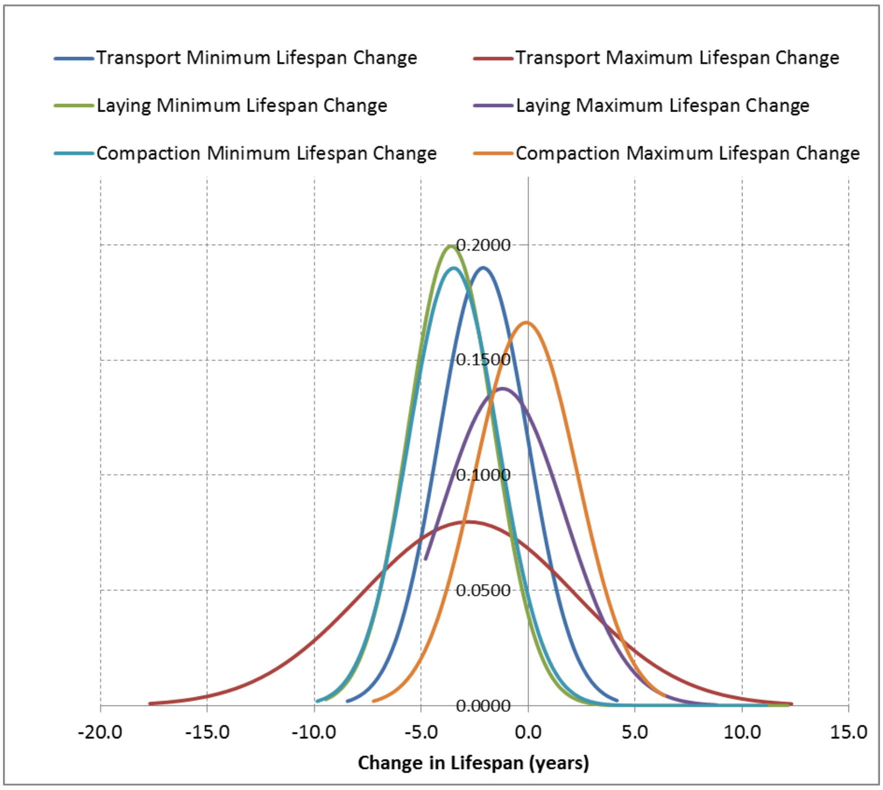

Figure 2 HRA 35/14 F Surf 40/60 Temperature of materials response

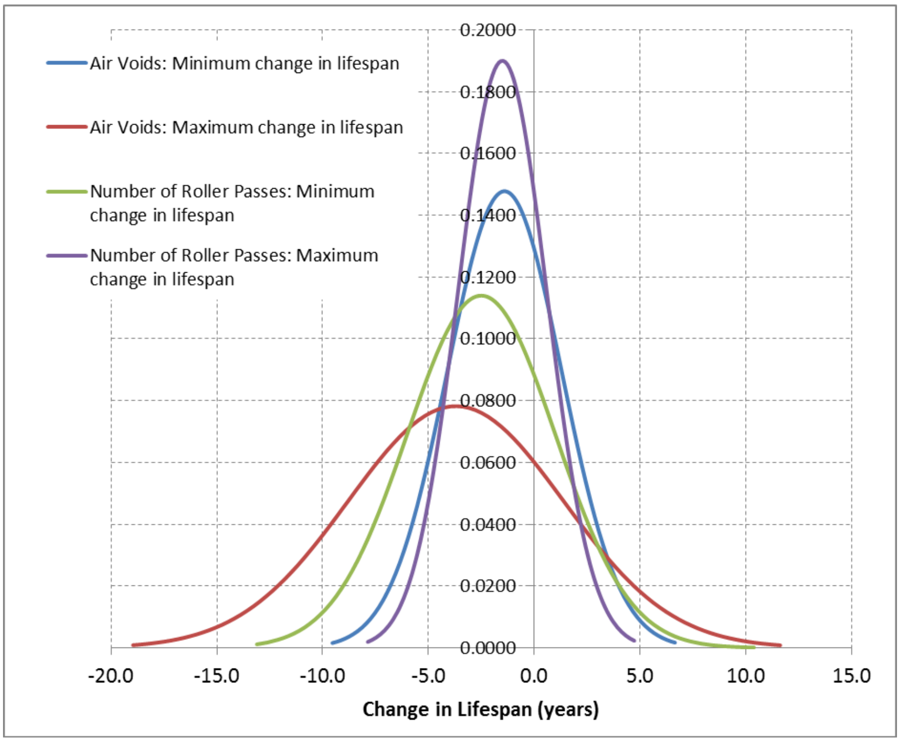

Figure 3 HRA 35/14 F Surf 40/60 Compaction

Figure 3 shows that maximum air voids were likely to cause greatest effect on the lifespan of the material; however industry opinion shows variation in response. By comparison number of roller passes shows a confident response from industry.

Figure 4 shows that compaction is likely to have greatest effect on lifespan both positively and negatively closely followed by laying equipment, this aligns with responses relating to material temperature. Transportation equipment is shown to have least likely effect on the lifespan of the material.

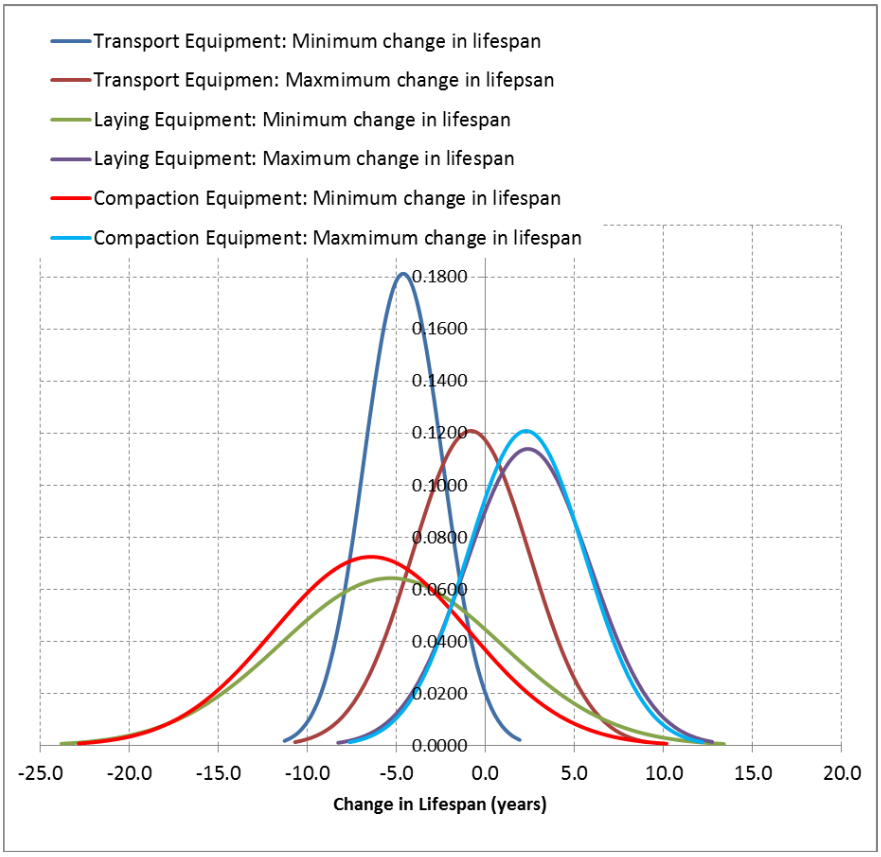

Figure 4 HRA 35/14 F Surf 40/60 Equipment response

Response regarding joints in the material, Figure 5, remains consistent as views from industry demonstrate confidence with small deviations from the mean for both construction and number of joints. Hot matched joints have greatest positive effect on lifespan of the material, whilst large numbers of joints and cold unpainted joints are confirmed as having large negative effects on lifespan.

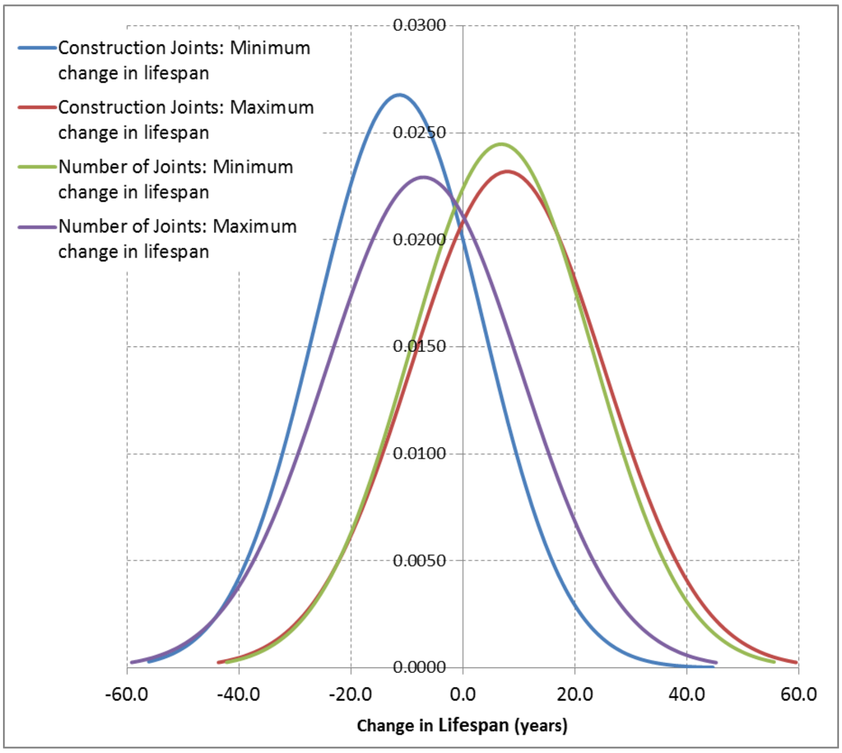

Figure 5 HRA 35/14 F Surf 40/60 Joint response

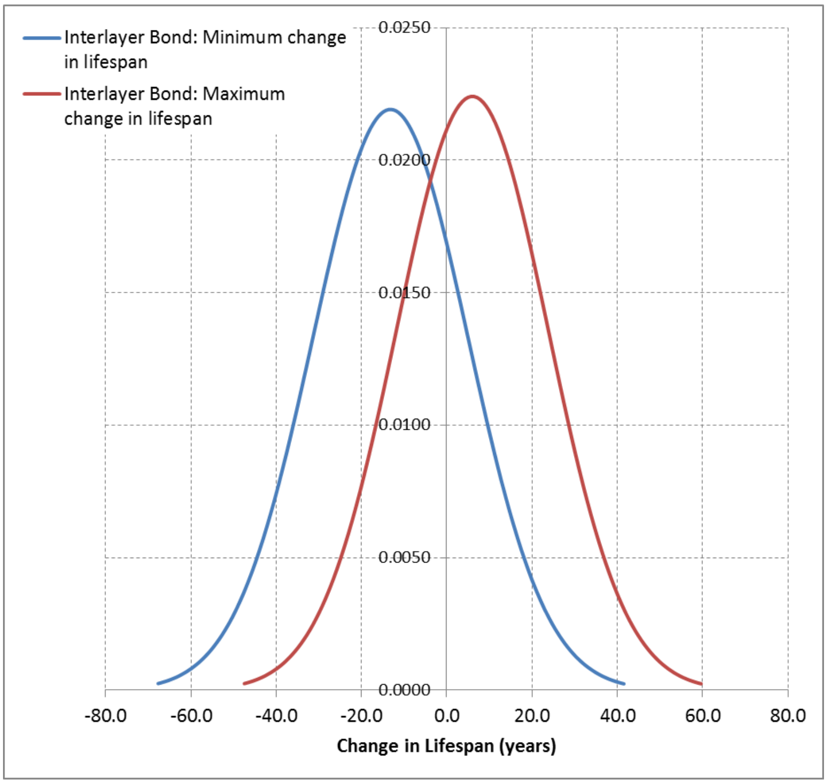

Figure 6 HRA 35/14 F Surf 40/60 Bond response

Interlayer bond has shown to be another key quality parameter, Figure 6 clearly demonstrates there is a quantifiable difference when relating amount of bond coat to lifespan of material, with increased bond coat providing an enhancement of lifespan of the material.

4.1.2 The Netherlands

As documented in report 1.1a, the most popular surfacing material in the Netherlands was ZOAB 16+, as such this was the material chosen as the focus of the questionnaire responses. In total 3 responses from industry were obtained at the time of writing. Surprisingly the maximum and minimum expected lifespans for the material had wide variation in response, Figure 7 whereas the expected lifespan had a small standard deviation from the mean. This could be as a result of small sample size or restricted area of expertise questioned as all three responses came from contractors.

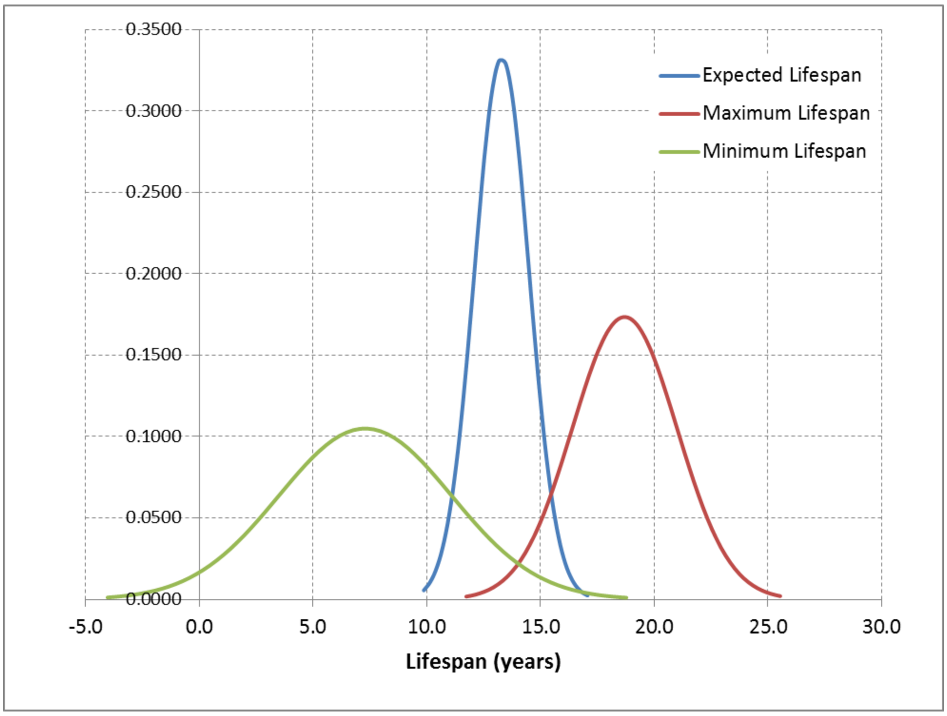

Figure 7 ZOAB 16+ lifespan responses

Figure 8 shows a high confidence in response regarding temperature of materials during laying illustrating that this can have a small negative effect on lifespan. Transporting and compacting materials at the lower end of their target temperature range is also confirmed as having a negative effect on lifespan.

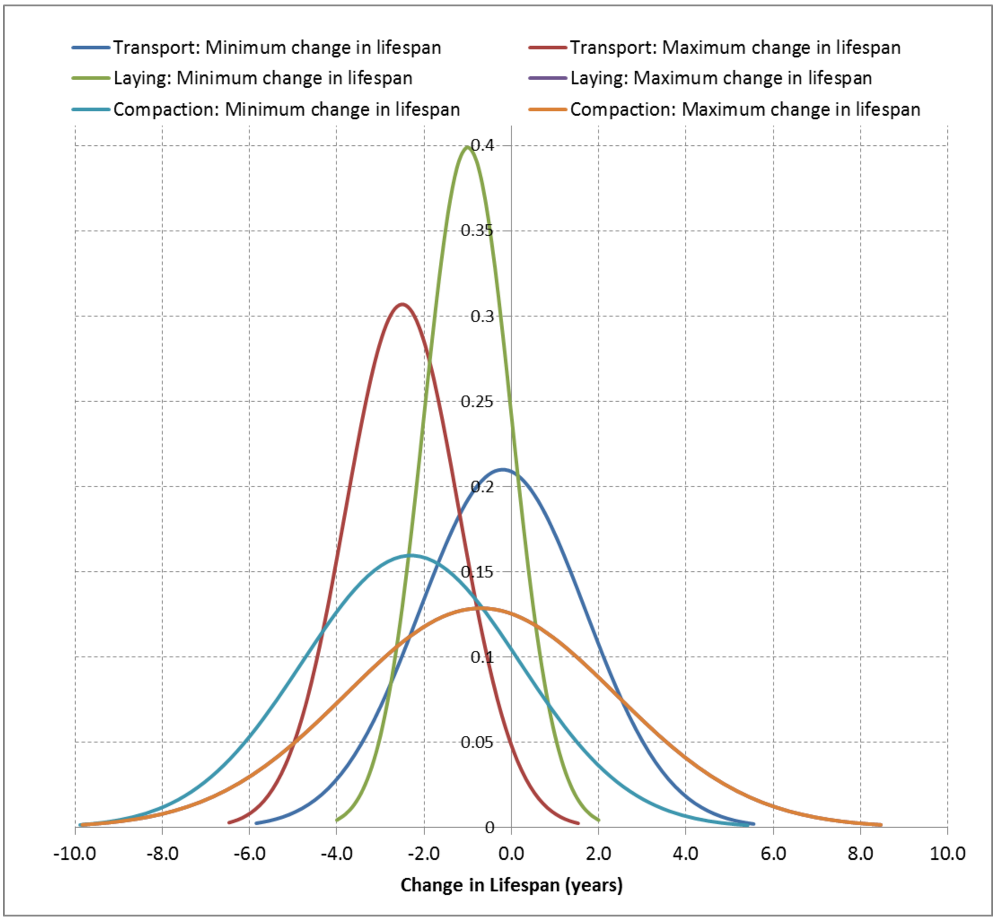

Figure 8 ZOAB 16+ temperature response

Figure 9 shows that industry are confident that air voids and number of roller passes have an effect on lifespan showing that insufficient roller passes and maximum air voids can have a negative effect on lifespan.

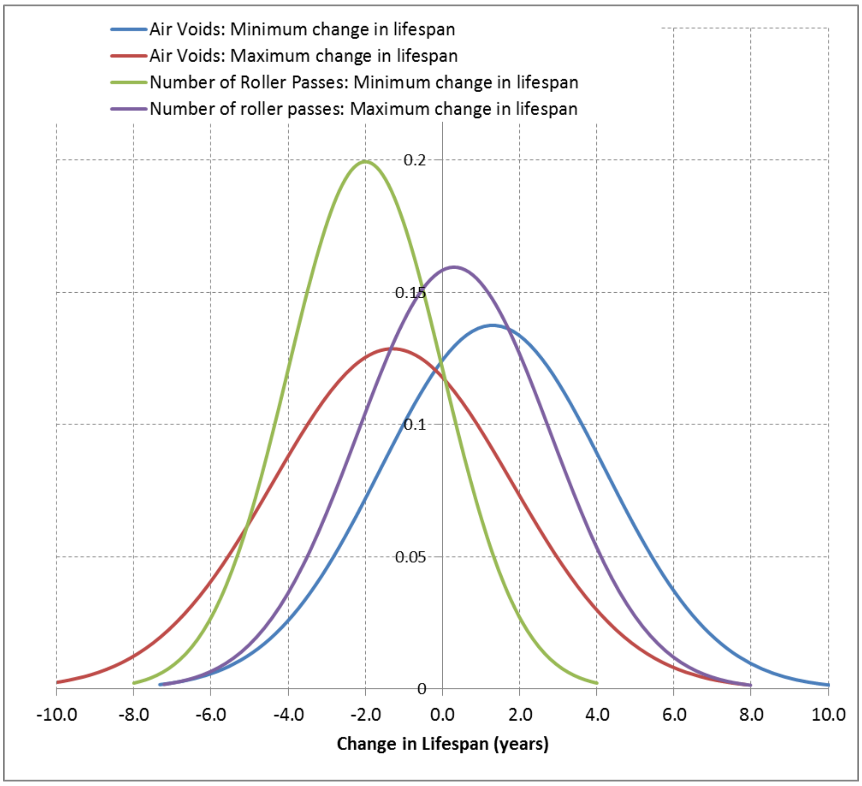

Figure 9 ZOAB 16+ Compaction response

Figure 10 shows much more variation in response regarding the effect on lifespan in relation to equipment. What is clear however is that use of 'intelligent' equipment is viewed by industry as having a positive effect on lifespan of the material.

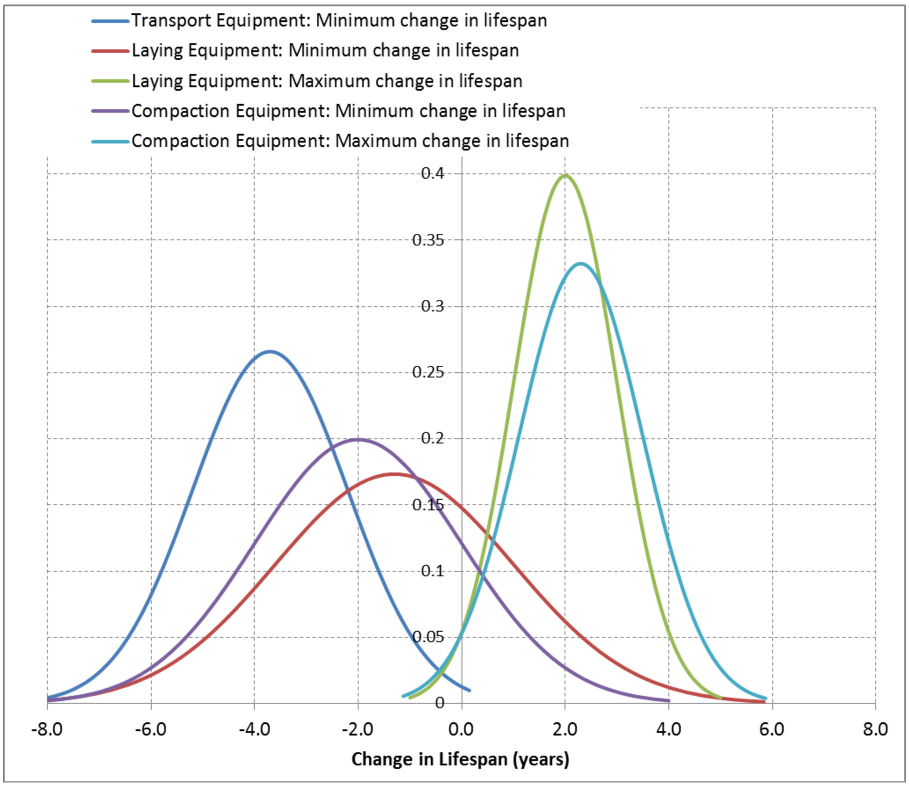

Figure 10 ZOAB 16+ Equipment response

Unfortunately insufficient data relating to the minimum number of joints has led to the exclusion of this parameter in Figure 11. However it is clear that construction joints can have a significant effect on lifespan. Industry results display confidence in assessing hot matched joints as enhancing lifespan.
Clear definition can be seen in Figure 12 regarding the effect of interlayer bond on lifespan. Results show increased bond coat can have a positive effect on life whilst reduced bond coat remains difficult to quantify in terms of effect on lifespan.

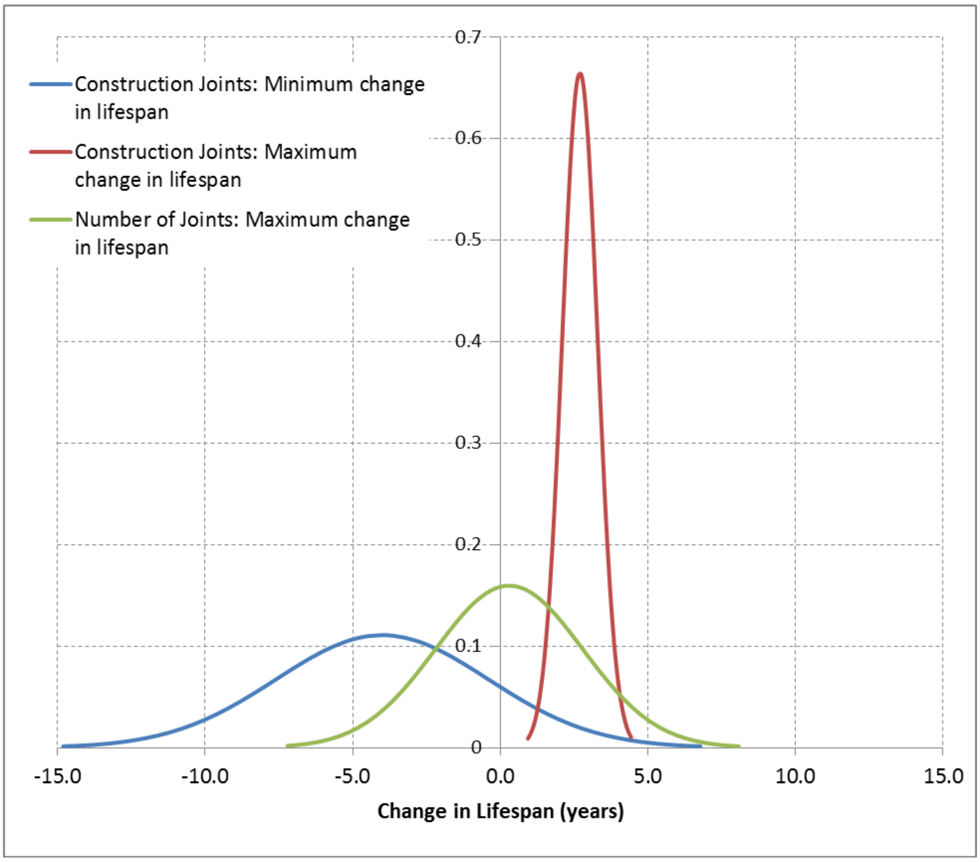

Figure 11 ZOAB 16+ Joints response

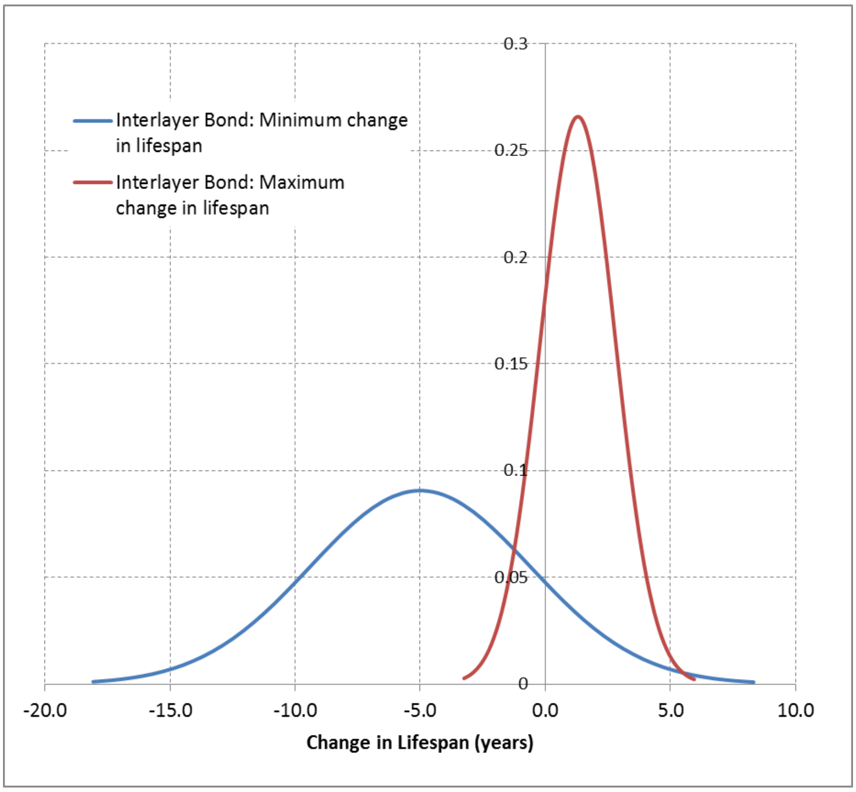

Figure 12 ZOAB 16+ Bond response

4.1.3 Slovenia

As documented in report 1.1a, the most commonly used asphalt mixture in Slovenia for surface course is AC11surf B50/70 for main roads and SMA8 PMB 45/80-65 for motorways as such these materials were chosen as the focus of the questionnaire responses. In total 3 responses from industry were obtained for the SMA8 and five for the AC11 material at the time of writing.

4.1.3.1 SMA 8 PMB 45/80-65

The response regarding expected, maximum and minimum lifespans of the material varied, it can be seen from Figure 13 that the views from industry for both minimum and expected lifespans were consistent.

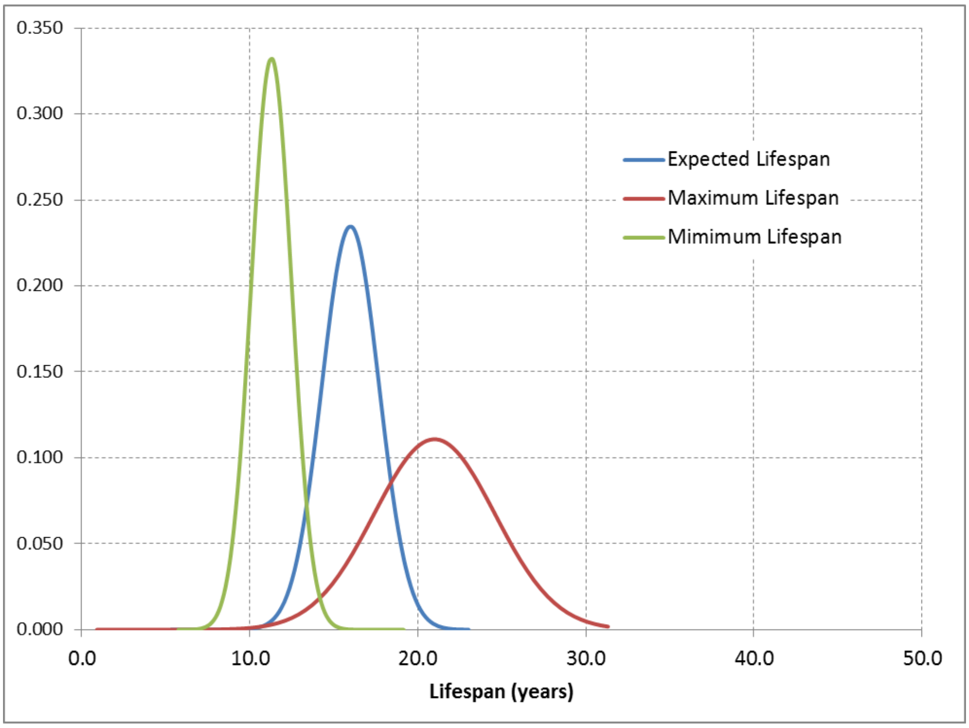

Figure 13 SMA8 Lifespans

Figure 14 shows a very consistent and confident approach indicating clearly that all aspects (transport, laying and compaction) relating to temperature of material can have a negative effect on lifespan.

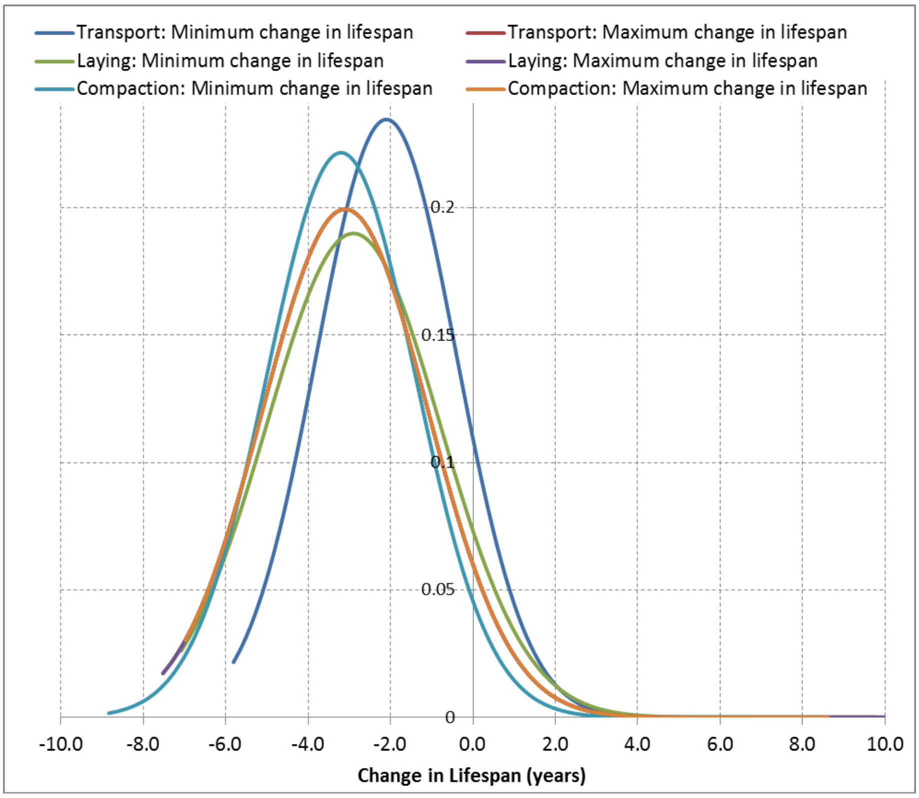

Figure 14 SMA8 temperature of materials response

The number of roller passes is viewed by industry as having greatest negative effect in relation to lifespan, as shown in Figure 15. Air void content is inextricably linked to roller passes therefore it could be inferred that a similar trend would follow.

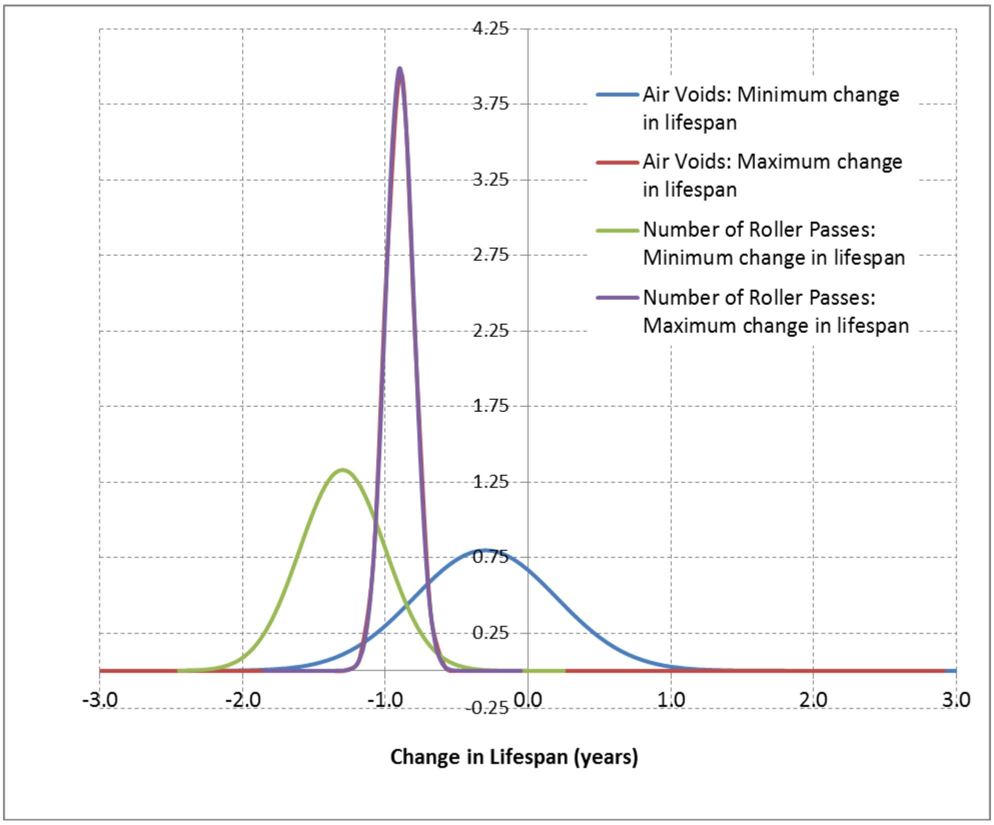

Figure 15 SMA8 compaction response

Figure 16 shows clear definition between results providing a strong indication that use of intelligent equipment can have a positive effect on lifespan of materials.

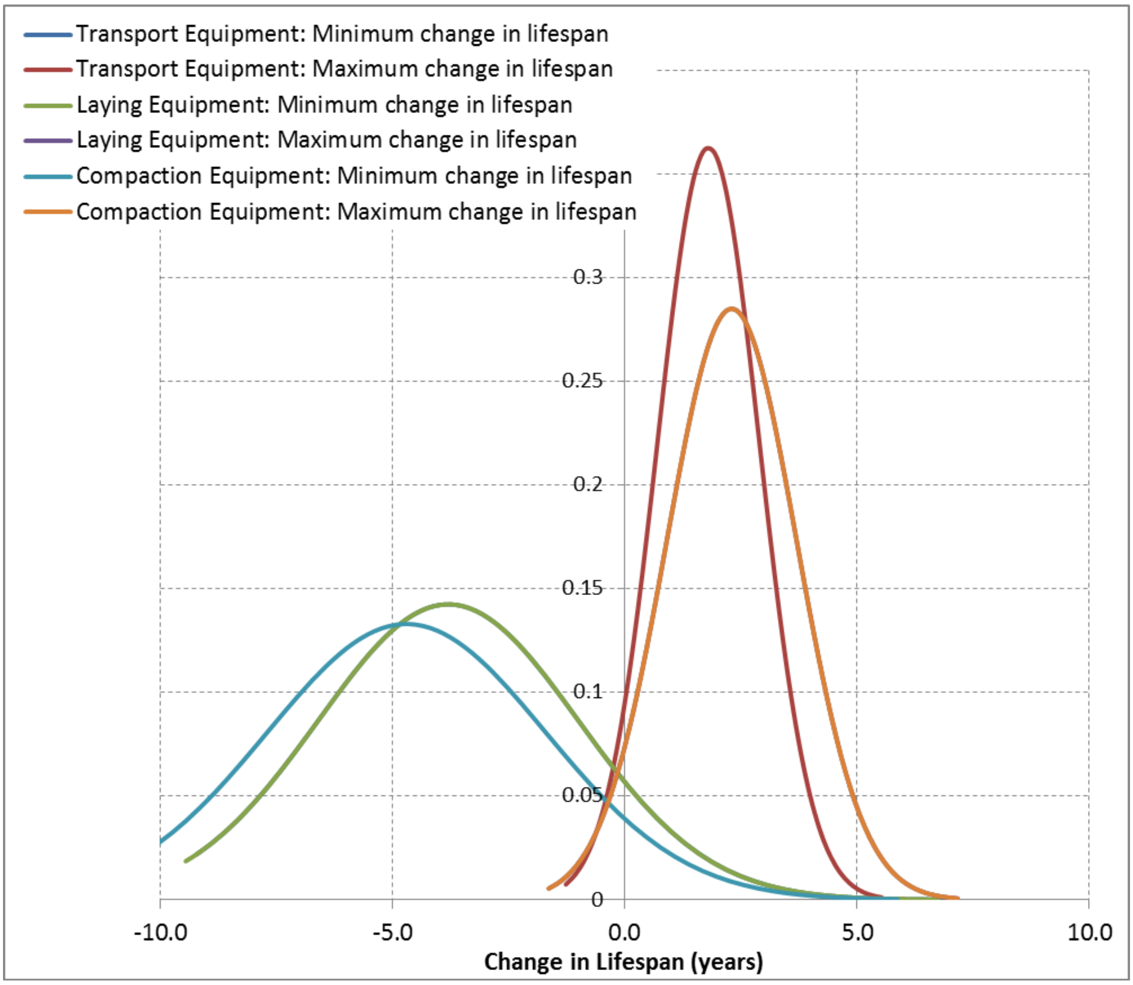

Figure 16 SMA8 Equipment response

Once again, hot matched joints are viewed as having greatest positive effect in relation to lifespan, see Figure 17. Maximum number of joints remains difficult to quantify in relation to lifespan.

As shown in Figure 18, and as seen previously for other countries increased bond coat significantly improves lifespan of materials.

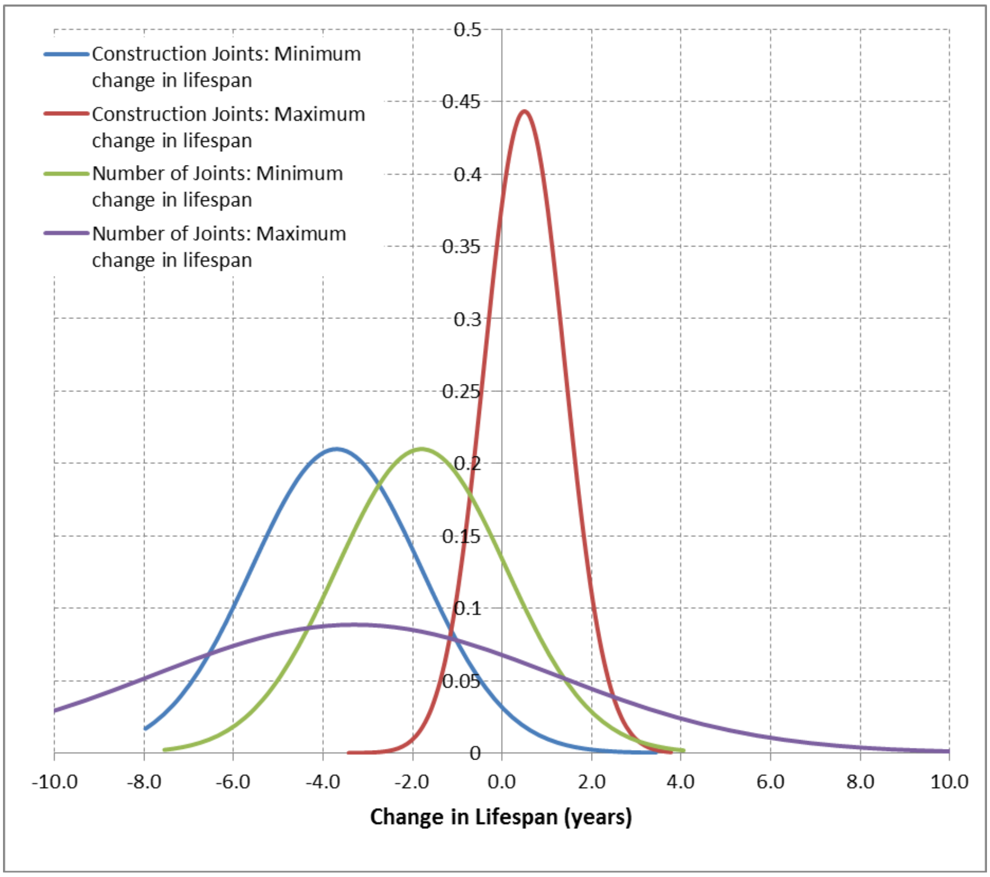

Figure 17 SMA8 Joints response

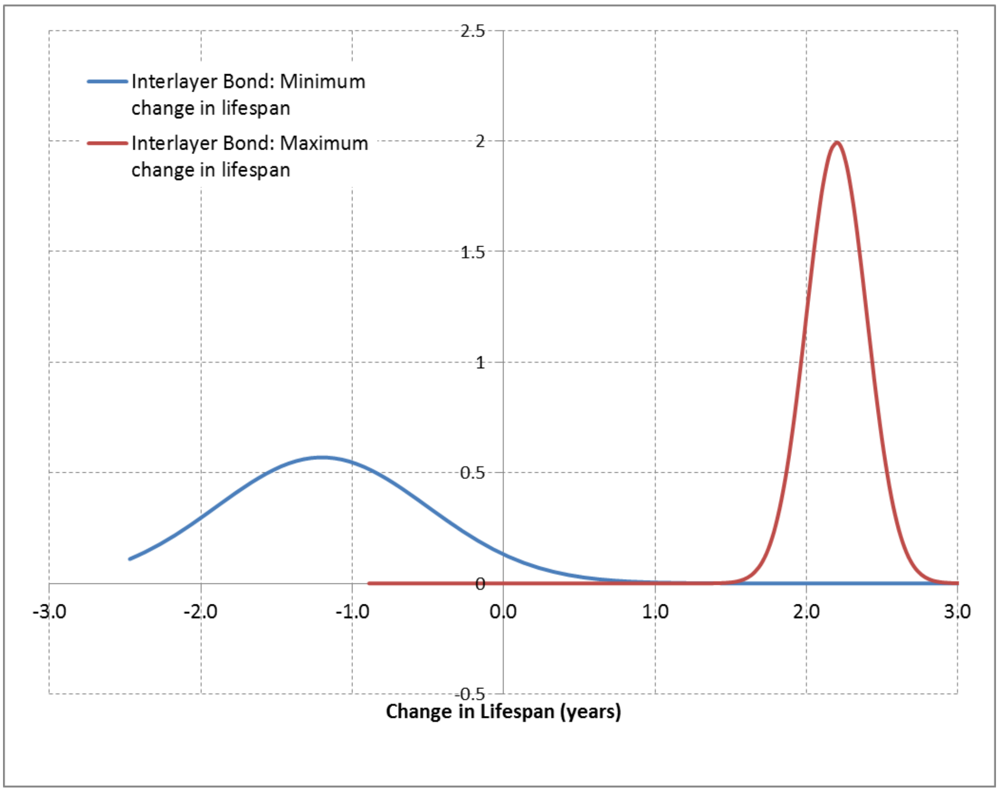

Figure 18 SMA8 Bond response

4.1.3.2 AC 11

The response regarding expected, maximum and minimum lifespans of the material varied, it can be seen from figure 19 that the views from industry for both minimum and expected lifespans were consistent with much less certainty regarding the maximum lifespan.

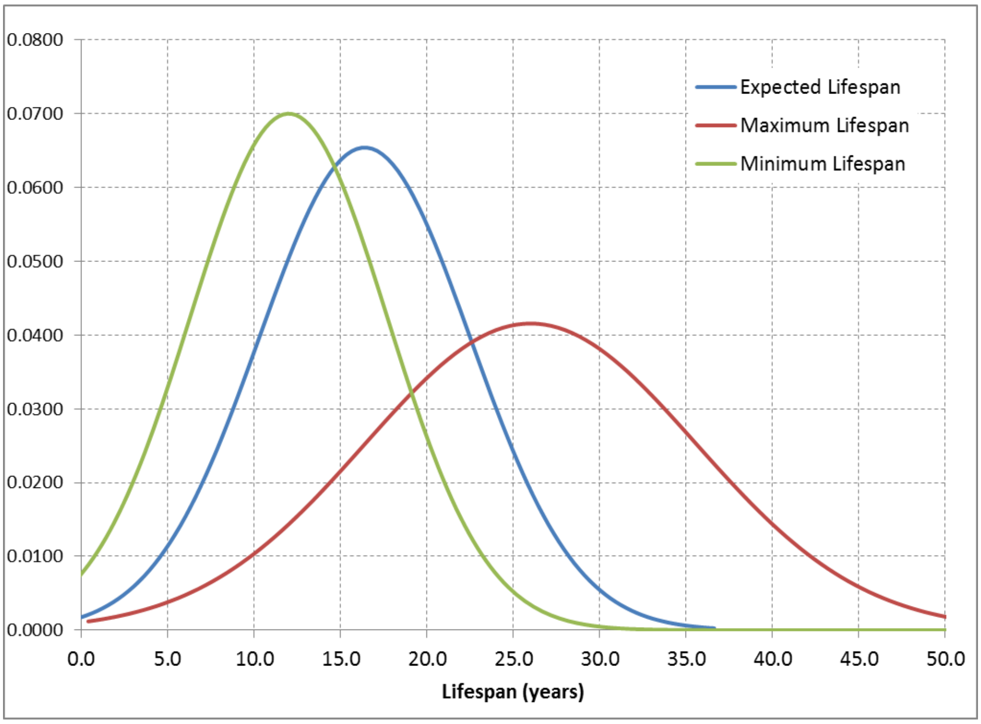

Figure 19 AC 11 Lifespan response

Whilst not all questions remained answered by every participant, those providing sufficient data for normal distributions curves can be found in figures 20 to 24. Figure 20 clearly shows a high degree of confidence in answers relating to temperature of materials during transport, laying and compaction. Whilst greatest confidence relates to transportation, laying and compaction are viewed as having greatest effect on lifespan, which is likely to be attributed to the open nature of the material during these phases of works.

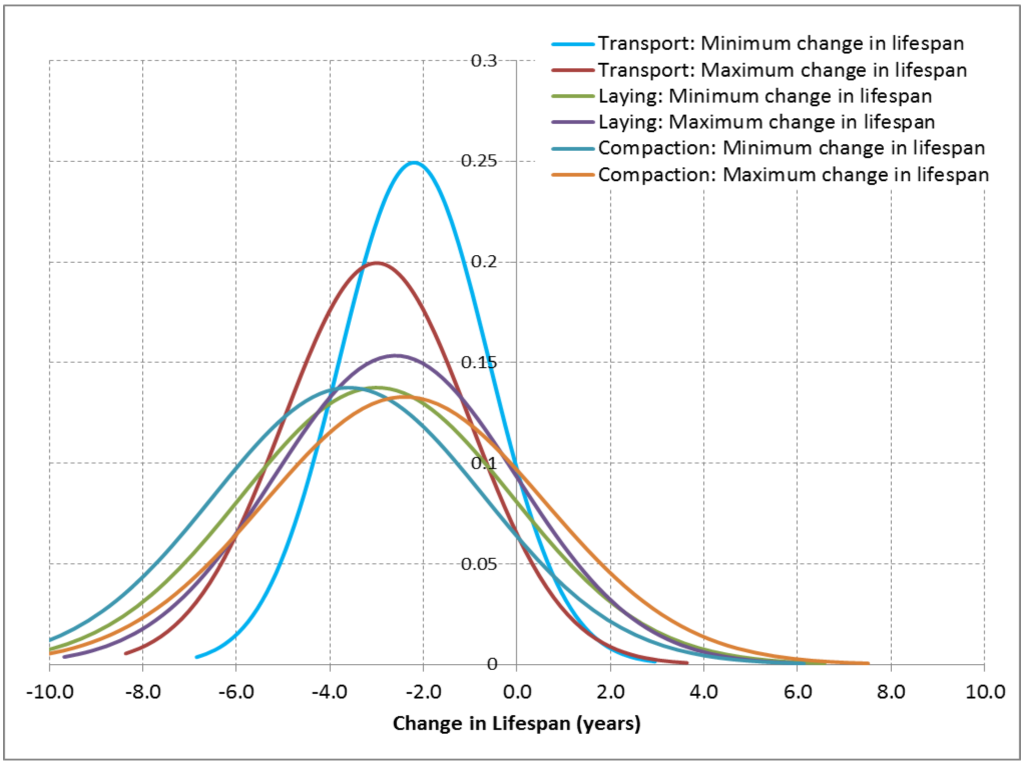

Figure 20 AC 11 Temperature of material

It is clear from Figure 21 that compaction is viewed as impacting on lifespan with greatest detrimental effect coming from minimum number of roller passes and maximum air void content.

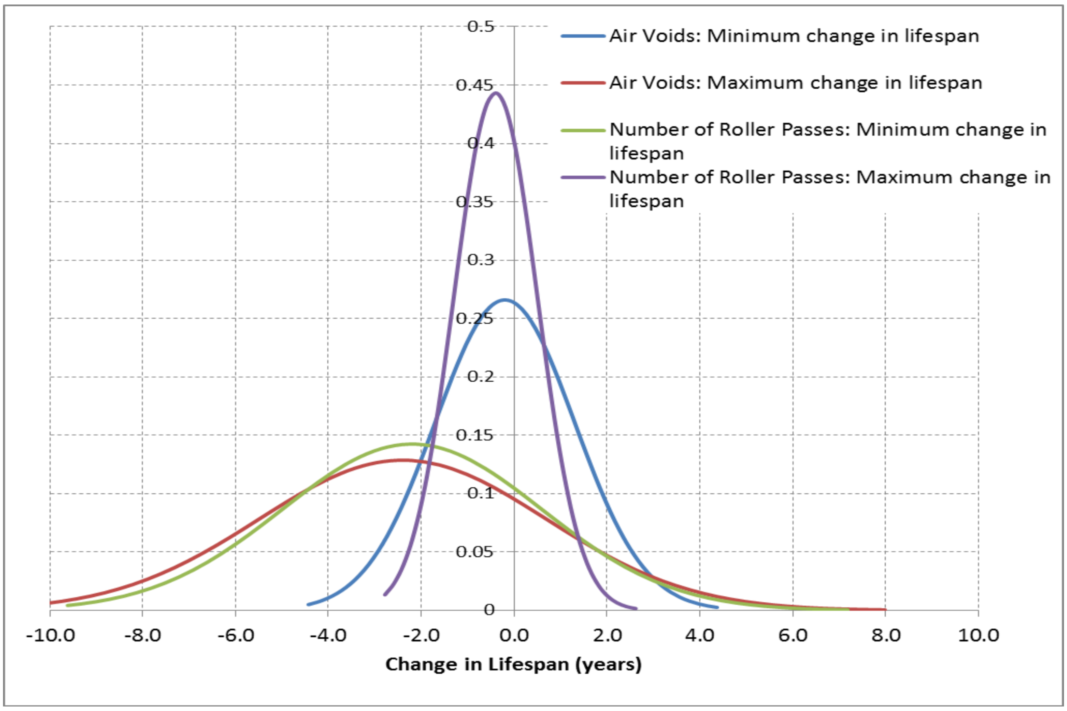

Figure 21 AC 11 Compaction response

Figure 22 shows variation in response to equipment used during the three main phases of works. However it is clear once again that use of intelligent equipment is believed to provide greatest positive effect with regards to lifespan on materials in relation to all three phases.

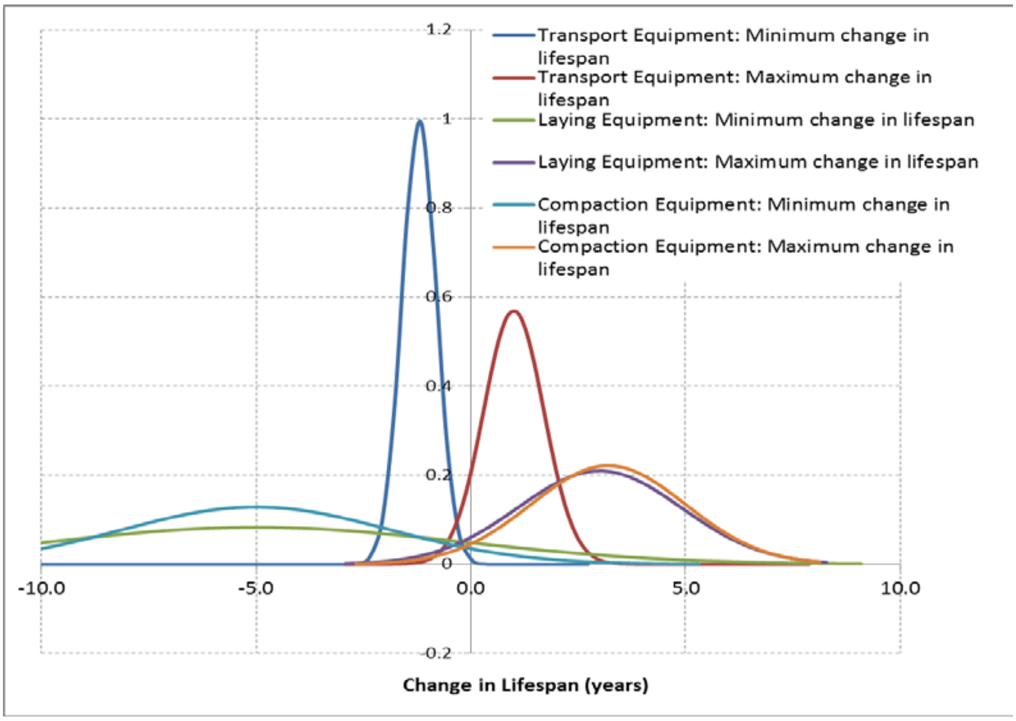

Figure 22 AC 11 Equipment responses

Once again, hot matched joints are viewed as having greatest positive effect in relation to lifespan, coupled with minimum number of joints, as shown in Figure 23.

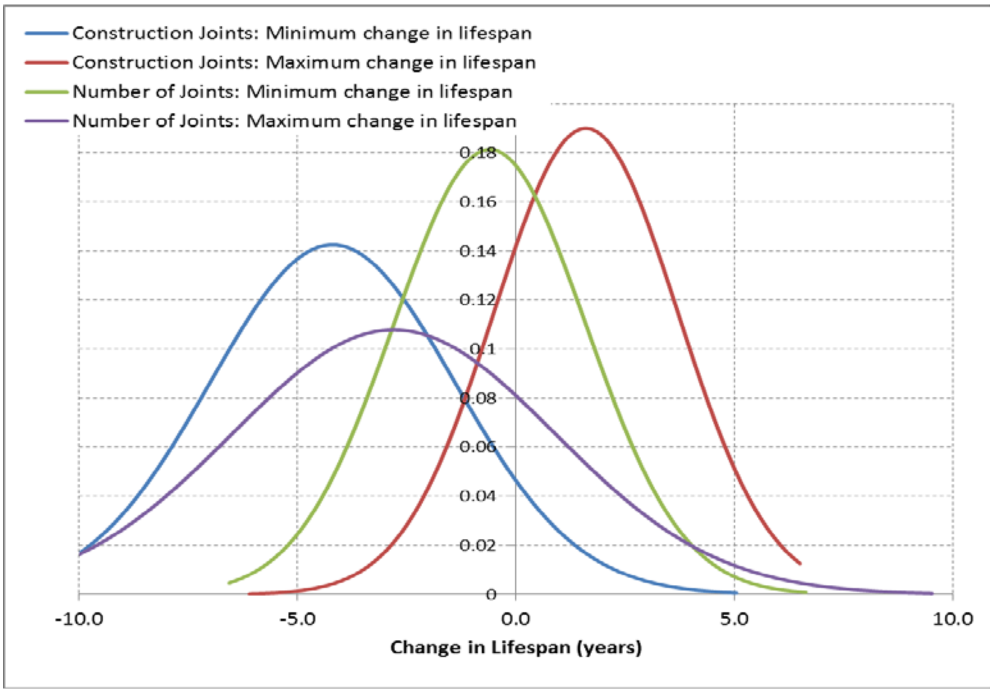

Figure 23 AC 11 Joints responses

As shown in Figure 24, and as seen previously for other countries increased bond coat significantly improves lifespan of materials.

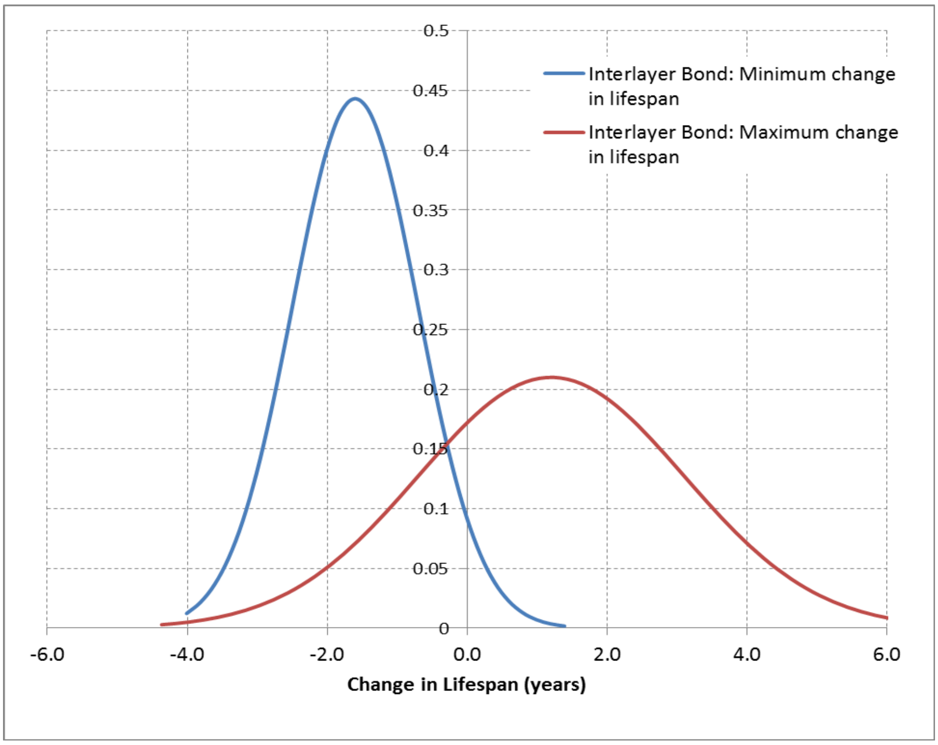

Figure 24 AC 11 Bond responses

5 WP1 workshop feedback

Following industry feedback from the questionnaires, workshops were held in each of the project partner countries to assess the accuracy and understanding of the tool, parameters and associated bandwidths proposed. Feedback was obtained from the England, Ireland and Netherlands and can be found reported in the form of minutes in Appendix E, F and G respectively and highlights the complex nature and concerns relating to implementing such a tool. Feedback from Slovenia will be reported in WP4 as feedback is to be obtained following site trials.

6 Conclusions

The questionnaire was developed to capture and quantify information from experts based on their experience and knowledge of the influence of construction parameters on the service life performance. Following consultation with industry it is clear that the parameters identified in this study have an effect on lifespan of materials. It is also apparent that some of those parameters are difficult to quantify in relation to life and many remain inextricably linked. From the industry questionnaires reviewed we can conclude that despite the country or material many of the parameters effecting quality are the same and measures such as adhering to temperatures, use of intelligent equipment, increase in bond coat and number of roller passes are all viewed as having a positive contribution to increasing life.

Further analysis of the results of this study will be reported in WP2.

7 Acknowledgement

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Appendix A: Relation Matrix

		Function											Safety	Performance	Service
		Skid Resistance		Noise Level		Ride Quality		Texture		Structural Stability (Stiffness)		Fatigue Resistance			
		Degradation Mechanisms													
Degradation Factors (combination of asphalt and pavement durability)	Phase	Rutting	Ravelling/Fretting	Cracking	Bleeding/Fatting Up	De-Bonding	Ageing (UV)	Stripping	Water Ingress/ Moisture Damage				Influenced/Interdependent on		
Temperature			X					X	X						
	T	L	L	L	L	L	L	L	L						
	L	H	H	M	M	M	L	M	M						
	C	M	H	M	M	H	L	H	H						
Environment			X	X				X							
....Ambient Temperature <5C	T	L	L	L	L	L	L	L	L						
....Wind Chill >15mph (or 24km/h)	L	M	M	M	L	M	L	L	L						
....Ambient Temperature <5C	L	M	M	M	L	M	L	M	L						
....Rainfall	L	L	L	L	L	M	L	M	H						
....Wind Chill >15mph (or 24km/h)	C	M	M	M	M	M	L	M	L						
....Ambient Temperature <5C	C	M	M	M	M	M	L	M	M						
....Rainfall	C	M	M	M	M	M	L	M	H						
Compaction		X		X			X		X				Environmental (wind speed, solar, ground and air temp), Aggregate and Binder factors, Lift thickness, type and number of roller passes, speed and timing of rollers, mix temperature, haulage time and distance		
....Void content	C	H	H	H	M	M	L	M	H						
....Number of roller passes	C	L	H	M	M	M	L	L	M						
Equipment															
....Basic equipment (no insulation)	T	L	L	L	L	L	L	M	L						
....Conventional equipment (thermal insulation)	T	L	L	L	L	L	L	L	L						
....Intelligent equipment (temperature monitoring)	T	L	L	L	L	L	L	L	L						
....Basic equipment (lightweight roller)	L	H	M	H	M	H	L	M	M						
....Conventional equipment (choice of roller)	L	M	M	M	M	M	L	L	L						
....Intelligent equipment (temperature plots)	L	M	M	M	M	M	L	L	L						
....Basic equipment (no vibratory screed)	C	H	H	H	H	H	L	M	L						
....Conventional equipment (vibratory screed)	C	M	M	M	M	M	L	L	L						
....Intelligent equipment (laserline and gps)	C	L	L	L	L	L	L	L	L						
Workmanship															
....New inexperienced operatives	T	L	L	L	L	L	L	L	L						
....Trained operatives	T	L	L	L	L	L	L	L	L						
....Experienced operatives	T	L	L	L	L	L	L	L	L						
....New inexperienced operatives	L	M	M	M	M	M	L	M	M						
....Trained operatives	L	M	M	M	M	M	L	M	M						
....Experienced operatives	L	M	M	M	M	M	L	M	M						
....New inexperienced operatives	C	H	H	H	H	H	L	H	H						
....Trained operatives	C	H	H	H	H	H	L	H	H						
....Experienced operatives	C	H	H	H	H	H	L	H	H						
Travel time and delays													(In relation to cooling rate) Layer thickness, air temperature. Base temperature, base moisture content, mix laydown temperature, wind velocity, amount of sunshine		
....Haulage time from the plant	T	L	L	L	L	L	H	L	L						
....Queue to offload (in relation to leaving the asphalt plar	L	M	H	M	M	M	H	L	L						
....Waiting at paver for next load	C	M	H	M	M	M	H	L	M						
Joints			X	X					X				Poor compaction, low binder content, over raking at the joint.		
....Hot matched or warm painted	L	L	L	L	L	L	L	L	L						
....Cold trimmed and painted	L	L	M	M	L	M	L	L	M						
....Cold and unpainted	L	L	H	H	L	H	L	L	H						
....Number of joints	L	L	H	M	L	H	L	L	M						
Interlayer bond		X		X		X		X	X						
....Contaminated surface	L	L	H	L	L	H	L	M	H						
....No bond coat	L	L	H	L	L	H	L	H	H						
....Target bond coat +0.2l/m^3	L	L	M	L	L	M	L	M	M						
....Target bond coat +0.4l/m^3	L	L	L	L	L	L	L	L	L						

Appendix B: Industry questionnaire

CEDR
Conférence Européenne des Directeurs des Routes
Conference of European Directors of Roads

Section 1: Please complete dark grey cells

		Comments
Name		
Country	England	
Surface Course Type (Based on EN 13108)	HRA 35/14 F surf 40/60	
Expected Lifespan of the material (years)		
Maximum lifespan of chosen material (years)		Maximum lifespan you would expect to see.
Minimum lifespan of chosen material (years)		Minimum lifespan you would expect to see.
Area of expertise/Job Function		(e.g. Consultant, materials supplier, contractor, equipment provider)

Section 2:

a. Please complete columns C to G in the dark grey cells. Please insert a single value in each cell rather than a range.
b. Please use the comments section if want to include addtional explanation of an answer.
b. If you feel you are not confident about answering a certain question, you can make a note in the comments section and leave the answer cell blank.
c. The questionnaire aims to gather knowledge of personal experience. Please do not refer to literature for answers.

Factor	Phase, T = Transport, L = Laying, C = Compaction	Optimum (Ideal value for this property)	Minimum (Lowest value you would ever expect to see)	Maximum (Greatest value you would ever expect to see)	Change in lifespan: extension (+) or reduction (-) — Change in Lifespan for minimum (years)	Change in Lifespan for maximum (years)	Comments
Temperature of material	T						
	L						
	C						
Weather							
....Ambient Temperature (°C) (assume average haulage dist.)	T						
....Wind Speed (km/h)	L						
....Ambient Temperature (°C)	L						
....Rainfall	L	no	no	yes			
....Wind Speed (km/h)	C						
....Ambient Temperature (°C)	C						
....Rainfall	C	no	no	yes			
Compaction							
....Void Content (%)	C						
....Number of roller passes	C						
Equipment							
(assume average haulage distance)	T	Thermal insulation	No insulation	Temperature conditioned			
	L	Commonly used	No Vibratory screed	Intelligent paver (gps) with feedback			
	C	Commonly used	Lightweight roller	Intelligent roller with feedback			
Workmanship	T	Trained	Inexperienced	Experienced			
	L	Trained	Inexperienced	Experienced			
	C	Trained	Inexperienced	Experienced			
Travel time and delays (with an insulated truck)							
....Haulage time from the plant (minutes)	T						
....Queue to offload (time delay incurred on site) (minutes)	L						
....Waiting at paver for next load (minutes)	C						
Joints (longitudal joints)							
....Construction	L	Cold trimmed and painted	Cold and unpainted	Hot matched			
....Number of joints (2 lane carraigeway with shoulders)	L						
Interlayer bond							
....Amount (g/m2)*	L		no bond coat				
*what kind of bond is used? Add in the comment column							

Appendix C: Industry questionnaire – Summary by Country

UK and Ireland response

UK and Ireland summary responses Appendix C

Surface Course Type (Based on EN 13108)

HRA 35/14 F surf 40/60

	England									Analysis England		Ireland					Analysis Ireland		UK Analysis	
	Consultant	Consultant	Consultant	Consultant	Contractor	LA Lab Manager	Consultant	Consultant	LA Mat Eng	**Average**	**Standard Deviation**	Consultant (Ex Mat Sup)	NRA - Engineer	Overlay Eng	NRA PM	Quality Co-ordinator	**Average**	**Standard Deviation**	**Average**	**Standard Deviation**
Expected Lifespan of the material (years)	20	20	20	15	15	25	20	20	25	**20.0**	**3.5**	20	20	20	20	10	**18.0**	**4.5**	**19.2**	**4.2**
Maximum lifespan of chosen material (years)	40	25	25	20	25	40	25	30	30	**28.9**	**7.0**	25	25	20	22	15	**21.4**	**4.2**	**25.2**	**6.3**
Minimum lifespan of chosen material (years)	5	15	12	10	8	15	15	7	12	**11.0**	**3.7**	5	15	15	15	8	**11.6**	**4.8**	**11.4**	**3.7**
Temperature of Material																				
T Optimum	140	180	180	180	175	160	180	170	175	**171.1**	**13.4**	180	160	155	160	180	**167.0**	**12.0**	**171.3**	**9.8**
T Minimum	130	160	150	155	150	140	150	160	140	**148.3**	**10.0**	150	140	140	130	160	**144.0**	**11.4**	**147.1**	**9.2**
T Maximum	190	195	190	210	195	190	200	190	195	**195.0**	**6.6**	200	190	180	170	190	**186.0**	**11.4**	**191.7**	**10.1**
T Effect of change in lifespan - minimum	-1	-1	-2	-5	-3	0	-1		-5	**-2.3**	**1.9**	0	0	-5	-2	0	**-1.4**	**2.2**	**-2.1**	**2.1**
T Effect of change in lifespan - maximum	-2	-4	-2	-6	-5	0	-3		5	**-2.1**	**3.4**	-1	0	-15	-2	-2	**-4.0**	**6.2**	**-2.8**	**5.0**
L Optimum	130	175	175	160	165	160	175	150	175	**162.8**	**15.2**	160	170	130	140		**150.0**	**18.3**	**160.0**	**14.8**
L Minimum	120	160	140	140	140	120	150	140	140	**138.9**	**12.7**	100	100	110	120		**107.5**	**9.6**	**127.3**	**17.9**
L Maximum	160	185	190	190	180	190	195	170	190	**183.3**	**11.5**	190	190	160	160		**175.0**	**17.3**	**182.3**	**12.9**
L Effect of change in lifespan - minimum	-1	-1	-2	-5	-3	0	-1		-5	**-2.3**	**1.9**	-5	-5	-5	-5		**-5.0**	**0.0**	**-3.6**	**2.0**
L Effect of change in lifespan - maximum	-1	-2	-2	-3	-5	0	-2		5	**-1.3**	**2.9**	0	0	-5	0		**-1.3**	**2.5**	**-1.2**	**2.9**
C Optimum	120	120	120	145	130	140	135	140	140	**132.2**	**10.0**	140	170	110	130		**137.5**	**25.0**	**136.4**	**15.2**
C Minimum	100	85	85	125	110	90	100	130	100	**102.8**	**16.2**	80	100	85	110		**93.8**	**13.8**	**101.4**	**16.3**
C Maximum	140	150	150	160	150	190	150	150	170	**156.7**	**15.0**	180	190	155	150		**168.8**	**19.3**	**163.2**	**16.5**
C Effect of change in lifespan - minimum	-2	-2	-5	-5	-3	0	-2		0	**-2.4**	**1.9**	-5	-5	-5	-5		**-5.0**	**0.0**	**-3.5**	**2.1**
C Effect of change in lifespan - maximum	-1	0	0	0	-1	0	0		5	**0.4**	**1.9**	0	0	-5	0		**-1.3**	**2.5**	**-0.1**	**2.4**
Weather																				
T *Ambient temperature ºC*																				
T Optimum	15	20	20	20	20	20	20		20	**19.4**	**1.8**	20	20	20	15	15	**18.0**	**2.7**	**19.1**	**2.0**
T Minimum	3	3	1	-1	1	5	-2		8	**2.3**	**3.2**	-3	5	5	8	10	**5.0**	**4.9**	**3.4**	**4.4**
T Maximum	30	30	NA	NA	30	40	3-		30	**32.0**	**4.5**	35	30	30	30	30	**31.0**	**2.2**	**31.9**	**3.7**
T Effect of change in lifespan - minimum	0	-2	-5	-4	-1	-15	-2		-5	**-4.3**	**4.7**	-2	-5		-2		**-3.0**	**1.7**	**-4.6**	**4.2**
T Effect of change in lifespan - maximum	0	NA	0	0	0	0	NA		0	**0.0**	**0.0**	0	0		0		**0.0**	**0.0**	**0.0**	**0.0**
L *Wind Speed (km/h)*																				
L Optimum	0	<10	<10	<5	0	0	<10	0	0	**0.0**	**0.0**	0	0	0			**0.0**	**0.0**	**0.0**	**0.0**
L Minimum	0	0	NA	0	0	0	0	0	0	**0.0**	**0.0**	0	0	0			**0.0**	**0.0**	**0.0**	**0.0**
L Maximum	40	40	60	20	20	15	40	10	30	**30.6**	**15.9**	30	30	25			**28.3**	**2.9**	**28.0**	**14.2**
L Effect of change in lifespan - minimum	0	0	0	0	0	0	0	0	0	**0.0**	**0.0**	0	0				**0.0**	**0.0**	**0.0**	**0.0**
L Effect of change in lifespan - maximum	-2	-5	-5	-4	-8	-15	-5	0	-5	**-5.4**	**4.2**	-5	-5				**-5.0**	**0.0**	**-5.8**	**4.0**
L *Ambient temperature ºC*																				
L Optimum	15	20	20	20	20	20	20	15	20	**18.9**	**2.2**	20	20	20	15		**18.8**	**2.5**	**19.1**	**2.0**
L Minimum	3	3	1	-1	1	5	-2	-3	8	**1.7**	**3.5**	-2	0	5	8		**2.8**	**4.6**	**1.8**	**4.0**
L Maximum	30	20	NA	NA	30	40	30	25	30	**29.3**	**6.1**	35	30	30	30		**31.3**	**2.5**	**31.1**	**4.2**
L Effect of change in lifespan - minimum	-1	-3	-3	-4	-5	-15	-3	0	-5	**-4.3**	**4.3**	-5	-5		-2		**-4.0**	**1.7**	**-4.7**	**4.0**
L Effect of change in lifespan - maximum	-2	0	0	0	0	0	0	0	0	**-0.2**	**0.7**	0	0		0		**0.0**	**0.0**	**0.0**	**0.0**
L *Rainfall*																				
L No = Optimum																				
L No = Minimum																				
L Yes = Maximum																				
L Effect of change in lifespan - minimum				0				0		**0.0**	**0.0**	0	0		0		**0.0**	**0.0**	**0.0**	**0.0**
L Effect of change in lifespan - maximum	-3	-5	-5	-5			-5	0	-15	**-5.4**	**4.6**	-2	-5		-2		**-3.0**	**1.7**	**-4.9**	**4.5**
C *Wind Speed (km/h)*																				
C Optimum	0	<10	<10	<5	0	0	<10	0	0	**0.0**	**0.0**	0	0	0			**0.0**	**0.0**	**0.0**	**0.0**
C Minimum	0	0	NA	0	0	0	0	0	0	**0.0**	**0.0**	0	0	0			**0.0**	**0.0**	**0.0**	**0.0**
C Maximum	40	40	60	20	20	15	40	10	30	**30.6**	**15.9**	30	30	25			**28.3**	**2.9**	**28.0**	**14.2**
C Effect of change in lifespan - minimum	0	0	0	0	0	0	0	0	0	**0.0**	**0.0**	0	0				**0.0**	**0.0**	**0.0**	**0.0**
C Effect of change in lifespan - maximum	-2	-5	-5	-4	-8	-15	-5	0	-10	**-6.0**	**4.5**	-5	-5				**-5.0**	**0.0**	**-6.3**	**4.2**
C *Ambient temperature ºC*																				
C Optimum	15	20	20	20	20	20	20	15	20	**18.9**	**2.2**	20	20	20	15		**18.8**	**2.5**	**19.1**	**2.0**
C Minimum	3	3	1	-1	1	5	3	-3	8	**2.2**	**3.2**	-2	0	5	2		**1.3**	**3.0**	**1.7**	**3.3**
C Maximum	30	30	NA	NA	30	40	30	25	30	**30.7**	**4.5**	-2	30	30	25		**20.8**	**15.3**	**26.4**	**11.5**
C Effect of change in lifespan - minimum	-1	-3	-3	-4	-5	-15	-3	0	-5	**-4.3**	**4.3**	-5	-5		-5		**-5.0**	**0.0**	**-5.0**	**3.9**
C Effect of change in lifespan - maximum	-2	0	0	0	0	0	0	0	0	**-0.2**	**0.7**	0	0		0		**0.0**	**0.0**	**0.0**	**0.0**

C	*Rainfall*																				
C	No = Optimum																				
C	No = Minimum																				
C	Yes = Maximum																				
C	Effect of change in lifespan - minimum				0						**0.0**		0			0		**0.0**	**0.0**	**0.0**	**0.0**
C	Effect of change in lifespan - maximum	-3	-5	-5	-5			-5		-15	**-6.3**	**4.3**	-2			-3		**-2.5**	**0.7**	**-5.8**	**4.7**
	Compaction																				
C	*Void Content (%)*																				
C	Optimum	4%	3%	3%	3%	4%	2%	2%	3%	4%	**0.0**	**0.0**	4%	3%		3%		**0.0**	**0.0**	**0.0**	**0.0**
C	Minimum	2%	2%	1%	1%	1%	2%	2%	2%	1%	**0.0**	**0.0**	1%	0%		2%		**0.0**	**0.0**	**0.0**	**0.0**
C	Maximum	8%	6%	5%	6%	6%	4%	4%	5%	8%	**0.1**	**0.0**	8%	7%		6%		**0.1**	**0.0**	**0.1**	**0.0**
C	Effect of change in lifespan - minimum	-1	0	-2	0	-3	0	0	0	-8	**-1.6**	**2.7**		0		0		**0.0**	**0.0**	**-1.4**	**2.7**
C	Effect of change in lifespan - maximum	-3	-3	-3	-4	-5	0	-3	4	-15	**-3.6**	**5.1**		-5		-2		**-3.5**	**2.1**	**-3.7**	**5.1**
C	*Number of Roller Passes*																				
C	Optimum	5				6	8	4		NA	**5.8**	**1.7**								**6.0**	**2.0**
C	Minimum	3				2	8	3		NA	**4.0**	**2.7**								**4.3**	**3.2**
C	Maximum	8				10	8	NA		NA	**8.7**	**1.2**								**9.0**	**1.4**
C	Effect of change in lifespan - minimum	-2				-5	0			NA	**-2.3**	**2.5**								**-2.5**	**3.5**
C	Effect of change in lifespan - maximum	-1				-3	0			NA	**-1.3**	**1.5**								**-1.5**	**2.1**
	Equipment																				
T	Thermal Insulation = Optimum																				
T	No Insulation = Minimum																				
T	Temperature Coniditioned = Maximum																				
T	Effect of change in lifespan - minimum	-2	-3	-3	-5	-5	-5	-3		-10	**-4.5**	**2.5**	-2	-5		-5	-3	**-3.8**	**1.5**	**-4.6**	**2.2**
T	Effect of change in lifespan - maximum	-1	0	0	-10	0	0	0		0	**-1.4**	**3.5**	0	0		0	2	**0.5**	**1.0**	**-0.8**	**3.3**
L	Commonly Used = Optimum																				
L	No Vibratory Screed = Minimum																				
L	Intelligent paver (gps with feedback) = Maximum																				
L	Effect of change in lifespan - minimum	-3	-2	-2	0	-1	-15	-2		-15	**-5.0**	**6.2**	-2	-5				**-3.5**	**2.1**	**-5.3**	**6.2**
L	Effect of change in lifespan - maximum	2	2	2	0	0	10	2		5	**2.9**	**3.3**	0	0				**0.0**	**0.0**	**2.4**	**3.5**
C	Commonly Used = Optimum																				
C	Lightweight Roller = Minimum																				
C	Intelligent Roller with feedback = Maximum																				
C	Effect of change in lifespan - minimum	-3	-2	-2	-4	-3	-15	-2		-15	**-5.8**	**5.8**	-5	-10		-2		**-5.7**	**4.0**	**-6.4**	**5.5**
C	Effect of change in lifespan - maximum	2	2	2	0	0	10	2		5	**2.9**	**3.3**	0	0		2		**0.7**	**1.2**	**2.3**	**3.3**
	Workmanship																				
T	Trained = Optimum																				
T	Inexperienced = Minimum																				
T	Experienced = Maximum																				
T	Effect of change in lifespan - minimum	-2	-2	0	-6	0	-15	-2		-5	**-4.0**	**4.9**	0	0		-1	0	**-0.3**	**0.5**	**-2.9**	**4.8**
T	Effect of change in lifespan - maximum	2	0	0	0	0	0	0		0	**0.3**	**0.7**	0	0		0	0	**0.0**	**0.0**	**0.0**	**0.0**
L	Trained = Optimum																				
L	Inexperienced = Minimum																				
L	Experienced = Maximum																				
L	Effect of change in lifespan - minimum	-2	-4	-5	-6	-8	-15	-2	20	-20	**-4.7**	**11.1**	-10	-10		-2		**-7.3**	**4.6**	**-5.8**	**10.7**
L	Effect of change in lifespan - maximum	2	2	0	0	0	0	2	0	5	**1.2**		0	0		0		**0.0**	**0.0**	**0.7**	**1.6**
C	Trained = Optimum																				
C	Inexperienced = Minimum																				
C	Experienced = Maximum																				
C	Effect of change in lifespan - minimum	-2	-4	-5	-6	-8	-15	-2	20	-20	**-4.7**	**11.1**	-5	-10		-4		**-6.3**	**3.2**	**-5.5**	**10.5**
C	Effect of change in lifespan - maximum	2	2	0	0	0	0	2	0	5	**1.2**	**1.7**	0	0		0		**0.0**	**0.0**	**0.7**	**1.6**
	Travel Time																				
T	*Haulage from the plant*																				
T	Optimum	60	90	60	<60	0	45	90	30	30	**50.6**	**31.0**	5	1	30			**12.0**	**15.7**	**32.3**	**29.7**
T	Minimum	10	60	10	<60	10	15	60	5	15	**23.1**	**23.0**	0	20	10			**10.0**	**10.0**	**16.1**	**17.5**
T	Maximum	120	180	180	180	240	120	240	180	240	**186.7**	**46.9**	180	180	120			**160.0**	**34.6**	**186.0**	**44.3**
T	Effect of change in lifespan - minimum	2	0	0	0	0	0	0	0	0	**0.2**	**0.7**	0	0			0	**0.0**	**0.0**	**0.0**	**0.0**
T	Effect of change in lifespan - maximum	-2	-3	-2		-3	-15	-3	0	-5	**-4.1**	**4.6**	-5	-2			0	**-2.3**	**2.5**	**-3.9**	**4.5**
L	*Time to offload (queing on site)*																				
L	Optimum	10	30	30	<30	0	0	30	0	30	**16.3**	**15.1**	0	0	15			**5.0**	**8.7**	**11.7**	**14.6**
L	Minimum	0	0	0	<15	0	0	0	0	15	**1.9**	**5.3**	0	0	5			**1.7**	**2.9**	**2.2**	**5.1**
L	Maximum	60	120	120	300	60	10	120	30	180	**111.1**	**88.5**	240	180	60			**160.0**	**91.7**	**130.0**	**94.5**
L	Effect of change in lifespan - minimum	0	0	0	0	0	0	0	0	0	**0.0**	**0.0**	0	0				**0.0**	**0.0**	**0.0**	**0.0**

L	Effect of change in lifespan - maximum	-1	-3	-2		-1	-15	-3	0	-5	**-3.8**	**4.8**	-5	0			**-2.5**	**3.5**	**-3.9**	**4.9**
C	*Waiting at paver for next load*																			
C	Optimum	0	0	0	0	0	0	0	0	0	**0.0**	**0.0**	0	0	0		**0.0**	**0.0**	**0.0**	**0.0**
C	Minimum	0	0	0	<10	5	0	0	0	0	**0.6**	**1.8**	0	0	0		**0.0**	**0.0**	**0.6**	**1.7**
C	Maximum	30	45	30	60	15	10	60	5	20	**30.6**	**20.5**	60	5	15		**26.7**	**29.3**	**28.0**	**23.2**
C	Effect of change in lifespan - minimum	0	0	0	0	0	0	0	0	0	**0.0**	**0.0**	0	0			**0.0**	**0.0**	**0.0**	**0.0**
C	Effect of change in lifespan - maximum	-2	-4	-4		-3	-15	-4		-10	**-6.0**	**4.7**	-5	-5			**-5.0**	**0.0**	**-6.6**	**4.4**
	Joints																			
L	*Construction*																			
L	Cold trimmed and painted = Optimum																			
L	Cold and Unpainted = Minimum																			
L	Hot Matched = Maximum																			
L	Effect of change in lifespan - minimum	-5	-4	-5	-4	-5	-50	-4		-15	**-11.5**	**16.0**	-5	-10		-5	**-6.7**	**2.9**	**-11.4**	**14.9**
L	Effect of change in lifespan - maximum	5	2	3	0	-	50	2		5	**9.6**	**17.9**	5	0		-2	**1.0**	**3.6**	**7.9**	**17.2**
L	*Number of joints*																			
L	1 = Optimum																			
L	0 = Minimum																			
L	2 = Maximum																			
L	Effect of change in lifespan - minimum	4	0	0	0	0	50	0		0	**6.8**	**17.5**	5	5		1	**3.7**	**2.3**	**6.8**	**16.3**
L	Effect of change in lifespan - maximum	-2	0	0	-2	-3	-50	0			**-8.1**	**18.5**	0	0		-2	**-0.7**	**1.2**	**-7.1**	**17.4**
	Interlayer Bond																			
L	*Amount*																			
L	Optimum	0.25	0.35	0.35	0.25	0.15	0.35	0.35		0.35	**0.3**	**0.1**	0.35	0.2			**0.3**	**0.1**	**0.3**	**0.1**
L	No Bond = Minimum																			
L	Maximum	0.4	0.7	0.4	0.35	0.35	1	0.7		0.35	**0.5**	**0.2**	0.5	0.5			**0.5**	**0.0**	**0.5**	**0.2**
L	Effect of change in lifespan - minimum	-5	-4	-5			-50	-4			**-13.6**	**20.4**	-5	-10		-5	**-6.7**	**2.9**	**-13.2**	**18.2**
L	Effect of change in lifespan - maximum	0	2	0	0	0	50	2			**7.7**	**18.7**	0	-2		-2	**-1.3**	**1.2**	**6.0**	**17.8**

Netherlands response

Netherlands summary response: Appendix C

Surface Course Type (Based on EN 13108)

ZOAB+ (deel 7)

	GvB Contractor	BS Netherlands Contractor	JE Contractor	**Analysis Netherlands** **Average**	**Standard Deviation**
Expected Lifespan of the material (years)	12	14	14	13.3	1.2
Maximum lifespan of chosen material (years)	16	20	20	18.7	2.3
Minimum lifespan of chosen material (years)	9	3	10	7.3	3.8
Temperature of Material					
T Optimum	155	150	160	155.0	5.0
T Minimum	140	130	130	133.3	5.8
T Maximum	180	180	170	176.7	5.8
T Effect of change in lifespan - minimum	-1.5	-1	2	-0.2	1.9
T Effect of change in lifespan - maximum	-1.5	-4	-2	-2.5	1.3
L Optimum	150	150	145	148.3	2.9
L Minimum	135	130	120	128.3	7.6
L Maximum	175	175	160	170.0	8.7
L Effect of change in lifespan - minimum	-2	-1	0	-1.0	1.0
L Effect of change in lifespan - maximum	2	-4	0	-0.7	3.1
C Optimum	130	145	130	135.0	8.7
C Minimum	70	110	90	90.0	20.0
C Maximum	170	170	150	163.3	11.5
C Effect of change in lifespan - minimum	-5	-2	0	-2.3	2.5
C Effect of change in lifespan - maximum	2	-4	0	-0.7	3.1
Weather					
T *Ambient temperature ºC*					
T Optimum	25	20	20	21.7	2.9
T Minimum	5	0	0	1.7	2.9
T Maximum	35	NA		35.0	
T Effect of change in lifespan - minimum	-1	-5	0	-2.0	2.6
T Effect of change in lifespan - maximum	0	2	0	0.7	1.2
L *Wind Speed (km/h)*					
L Optimum	<3	<10	0	0.0	
L Minimum	0	0	0	0.0	0.0
L Maximum	>6	40	10	25.0	21.2
L Effect of change in lifespan - minimum	1	2	0	1.0	1.0
L Effect of change in lifespan - maximum	-1	-5	0	-2.0	2.6
L *Ambient temperature ºC*					
L Optimum	25	20	20	21.7	2.9
L Minimum	5	-2	10	4.3	6.0
L Maximum	35	NA	35	35.0	0.0
L Effect of change in lifespan - minimum	0	-5	0	-1.7	2.9
L Effect of change in lifespan - maximum	0	2	0	0.7	1.2
L *Rainfall*					
L No = Optimum					
L No = Minimum					
L Yes = Maximum					
L Effect of change in lifespan - minimum	0	0	0	0.0	0.0
L Effect of change in lifespan - maximum	0	<4	0	0.0	0.0
C *Wind Speed (km/h)*					
C Optimum	<3	<10	0	0.0	
C Minimum	0	0	0	0.0	0.0
C Maximum	>6	40	36	38.0	2.8
C Effect of change in lifespan - minimum	1	2	0	1.0	1.0
C Effect of change in lifespan - maximum	-3	-5	0	-2.7	2.5
C *Ambient temperature ºC*					
C Optimum	25	20	20	21.7	2.9
C Minimum	5	-2		1.5	4.9
C Maximum	35	NA	35	35.0	0.0

C	Effect of change in lifespan - minimum	-2	-7	0	-3.0	3.6
C	Effect of change in lifespan - maximum	-3	2	0	-0.3	2.5
C	*Rainfall*					
C	No = Optimum					
C	No = Minimum					
C	Yes = Maximum					
C	Effect of change in lifespan - minimum	0	0	0	0.0	0.0
C	Effect of change in lifespan - maximum	-1	-4	0	-1.7	2.1
	Compaction					
C	*Void Content (%)*					
C	Optimum	21%	20%	19%	0.2	0.0
C	Minimum	18%	15%	15%	0.2	0.0
C	Maximum	23%	26%	23%	0.2	0.0
C	Effect of change in lifespan - minimum	-2	3	3	1.3	2.9
C	Effect of change in lifespan - maximum	2	-4	-2	-1.3	3.1
C	*Number of Roller Passes*					
C	Optimum	5	8	10	7.7	2.5
C	Minimum	3	4	5	4.0	1.0
C	Maximum	10	20	20	16.7	5.8
C	Effect of change in lifespan - minimum	-2	-4	0	-2.0	2.0
C	Effect of change in lifespan - maximum	3	-2	0	0.3	2.5
	Equipment					
T	Thermal Insulation = Optimum					
T	No Insulation = Minimum					
T	Temperature Coniditioned = Maximum					
T	Effect of change in lifespan - minimum	-4	-5	-2	-3.7	1.5
T	Effect of change in lifespan - maximum	2	2	2	2.0	0.0
L	Commonly Used = Optimum					
L	No Vibratory Screed = Minimum					
L	Intelligent paver (gps with feedback) = Maximum					
L	Effect of change in lifespan - minimum	0	-4	0	-1.3	2.3
L	Effect of change in lifespan - maximum	2	3	1	2.0	1.0
C	Commonly Used = Optimum					
C	Lightweight Roller = Minimum					
C	Intelligent Roller with feedback = Maximum					
C	Effect of change in lifespan - minimum	-2	-4	0	-2.0	2.0
C	Effect of change in lifespan - maximum	3	3	1	2.3	1.2
	Workmanship					
T	Trained = Optimum					
T	Inexperienced = Minimum					
T	Experienced = Maximum					
T	Effect of change in lifespan - minimum	0	-4	-1	-1.7	2.1
T	Effect of change in lifespan - maximum	0	2	0	0.7	1.2
L	Trained = Optimum					
L	Inexperienced = Minimum					
L	Experienced = Maximum					
L	Effect of change in lifespan - minimum	-1	-4	-2	-2.3	1.5
L	Effect of change in lifespan - maximum	2	2	2	2.0	0.0
C	Trained = Optimum					
C	Inexperienced = Minimum					
C	Experienced = Maximum					
C	Effect of change in lifespan - minimum	-1	-8	-1	-3.3	4.0
C	Effect of change in lifespan - maximum	2	3	2	2.3	0.6
	Travel Time					
T	*Haulage from the plant*					
T	Optimum	<60	10	15	12.5	3.5
T	Minimum	0	0	0	0.0	0.0
T	Maximum	150	120	60	110.0	45.8
T	Effect of change in lifespan - minimum	2	0	1	1.0	1.0
T	Effect of change in lifespan - maximum	-2	-2	-1	-1.7	0.6

L	*Time to offload (queing on site)*					
L	Optimum	<30	10	0	5.0	7.1
L	Minimum	0	0	0	0.0	0.0
L	Maximum	60	240	30	110.0	113.6
L	Effect of change in lifespan - minimum	0	0	0	0.0	0.0
L	Effect of change in lifespan - maximum	-1	-2	0	-1.0	1.0
C	*Waiting at paver for next load*					
C	Optimum	0	5	0	1.7	2.9
C	Minimum	0	0	0	0.0	0.0
C	Maximum	30	15	2	15.7	14.0
C	Effect of change in lifespan - minimum	0	0	0	0.0	0.0
C	Effect of change in lifespan - maximum	-4	-2	0	-2.0	2.0
	Joints					
L	*Construction*					
L	Cold trimmed and painted = Optimum					
L	Cold and Unpainted = Minimum					
L	Hot Matched = Maximum					
L	Effect of change in lifespan - minimum	-1	-8	-3	-4.0	3.6
L	Effect of change in lifespan - maximum	3	3	2	2.7	0.6
L	*Number of joints*					
L	1 = Optimum					
L	0 = Minimum					
L	2 = Maximum					
L	Effect of change in lifespan - minimum	2	0	0	0.7	1.2
L	Effect of change in lifespan - maximum	-2	0	3	0.3	2.5
	Interlayer Bond					
L	*Amount*					
L	Optimum	300	300	400	333.3	57.7
L	No Bond = Minimum					
L	Maximum	500	700	600	600.0	100.0
L	Effect of change in lifespan - minimum	-3	-10	-2	-5.0	4.4
L	Effect of change in lifespan - maximum	1	0	3	1.3	1.5

Slovenia response

Slovenia summary response AC11: Appendix C

Surface Course Type (Based on EN 13108)

AC11surf B50/70 A2

		Quality Control, Contractor	Materials Supplier	Technology	Nadzorni	Nazdor	Laboratory	Analysis Average	Analysis Standard Deviation
	Expected Lifespan of the material (years)	20	15	20	12	25	10	17.0	5.7
	Maximum lifespan of chosen material (years)	30	25	40	15	30	20	26.7	8.8
	Minimum lifespan of chosen material (years)	10	10	20	10	15	5	11.7	5.2
	Temperature of Material								
T	Optimum	165	165	155	160	165	160	161.7	4.1
T	Minimum	155	155	145	140	155	140	148.3	7.5
T	Maximum	175	175	165	180	185	180	176.7	6.8
T	Effect of change in lifespan - minimum	-3	-2	-1	-1	-5	-2	-2.3	1.5
T	Effect of change in lifespan - maximum	-3	-3	-1	-1	-5	-5	-3.0	1.8
L	Optimum	155	155	155	155	165	155	156.7	4.1
L	Minimum	130	130	145	130	150	130	135.8	9.2
L	Maximum	175	175	165	180	180	180	175.8	5.8
L	Effect of change in lifespan - minimum	-3	-2	-1	-1	-8	-3	-3.0	2.6
L	Effect of change in lifespan - maximum	-3	-3	1	-1	-5	-5	-2.7	2.3
C	Optimum	155	155	155	150	165	150	155.0	5.5
C	Minimum	130	130	130	120	145	120	129.2	9.2
C	Maximum	175	175	165	170	185	180	175.0	7.1
C	Effect of change in lifespan - minimum	-3	-2	-2	-1	-8	-5	-3.5	2.6
C	Effect of change in lifespan - maximum	-3	-3	2	-1	-5	-5	-2.5	2.7
	Weather								
T	*Ambient temperature ºC*								
T	Optimum	25	25	25	25	25	20	24.2	2.0
T	Minimum	3	3	3	3	3	3	3.0	0.0
T	Maximum	36	36	35	40	36	40	37.2	2.2
T	Effect of change in lifespan - minimum	-2	-2	-2	0	-8	-4	-3.0	2.8
T	Effect of change in lifespan - maximum	0	0	0	0	3	0	0.5	1.2
L	*Wind Speed (km/h)*								
L	Optimum	0	0	0	0	0	0	0.0	0.0
L	Minimum	0	0	0	0	0	0	0.0	0.0
L	Maximum	50	50	36	50	50	50	47.7	5.7
L	Effect of change in lifespan - minimum	0	0	0	-1	0	0	-0.2	0.4
L	Effect of change in lifespan - maximum	-1	-3	-3	-1	-5	-5	-3.0	1.8
L	*Ambient temperature ºC*								
L	Optimum	25	25	25	25	25	20	24.2	2.0
L	Minimum	3	3	3	3	3	3	3.0	0.0
L	Maximum	36	36	25	40	36	40	35.5	5.5
L	Effect of change in lifespan - minimum	-2	-1	-2	-1	0	-4	-1.7	1.4
L	Effect of change in lifespan - maximum	0	-1	0	-1	-8	0	-1.7	3.1
L	*Rainfall*								
L	No = Optimum								
L	No = Minimum								
L	Yes = Maximum								
L	Effect of change in lifespan - minimum	0	0	0	0	0	0	0.0	0.0
L	Effect of change in lifespan - maximum	-4	-3	-4	-1	-9	-7	-4.7	2.9
C	*Wind Speed (km/h)*								
C	Optimum	0	0	0	0	5	0	0.8	2.0
C	Minimum	0	0	0	0	0	0	0.0	0.0
C	Maximum	50	50	36	50	40	50	46.0	6.3
C	Effect of change in lifespan - minimum	0	0	0	0	-8	0	-1.3	3.3
C	Effect of change in lifespan - maximum	-2	-3	-2	-2	3	-5	-1.8	2.6
C	*Ambient temperature ºC*								
C	Optimum		25	25	25	20	20	23.0	2.7
C	Minimum		3	3	3	9	3	4.2	2.7
C	Maximum		36	35	40	40	40	38.2	2.5
C	Effect of change in lifespan - minimum	0	-3	-2	-1	-8	-4	-3.0	2.8
C	Effect of change in lifespan - maximum	-4	0	0	0	3	0	-0.2	2.2
C	*Rainfall*								
C	No = Optimum								
C	No = Minimum								
C	Yes = Maximum								
C	Effect of change in lifespan - minimum	0	0	0	0	4	0	0.7	1.6
C	Effect of change in lifespan - maximum	-4	-6	-2	-1	0	-7	-3.3	2.8
	Compaction								
C	*Void Content (%)*								
C	Optimum	4.5	4.5%	5.0%	5.0%	4.5%	5.0%	0.8	1.8
C	Minimum	1.5	1.5%	2.0%	2.0%	1.5%	2.0%	0.3	0.6
C	Maximum	7.5	7.5%	8.5%	8.5%	7.5%	9.0%	1.3	3.0
C	Effect of change in lifespan - minimum	-1	0	2	-1	0	-2	-0.3	1.4
C	Effect of change in lifespan - maximum	-5	-1	-1	-1	-1	-8	-2.8	3.0
C	*Number of Roller Passes*								
C	Optimum	6	6	5	5	6	6	5.7	0.5
C	Minimum	4	4	4	3	4	1	3.3	1.2
C	Maximum	10	10	7	9	10	12	9.7	1.6
C	Effect of change in lifespan - minimum	-2	0	-2	-1	-1	-7	-2.2	2.5
C	Effect of change in lifespan - maximum	0	-1	1	-1	-1	0	-0.3	0.8

	Equipment								
T	Thermal Insulation = Optimum								
T	No Insulation = Minimum								
T	Temperature Coniditioned = Maximum								
T	Effect of change in lifespan - minimum	-2	-3	-2	-1	-10	-5	-3.8	3.3
T	Effect of change in lifespan - maximum	1	2	1	1	4	5	2.3	1.8
L	Commonly Used = Optimum								
L	No Vibratory Screed = Minimum								
L	Intelligent paver (gps with feedback) = Maximum								
L	Effect of change in lifespan - minimum	-3	-2	-1	-2	-10	-8	-4.3	3.7
L	Effect of change in lifespan - maximum	1	2	2	1	5	5	2.7	1.9
C	Commonly Used = Optimum								
C	Lightweight Roller = Minimum								
C	Intelligent Roller with feedback = Maximum								
C	Effect of change in lifespan - minimum	-3	-8	-3	-1	-8	-5	-4.7	2.9
C	Effect of change in lifespan - maximum	1	2	3	1	5	5	2.8	1.8
	Workmanship								
T	Trained = Optimum								
T	Inexperienced = Minimum								
T	Experienced = Maximum								
T	Effect of change in lifespan - minimum	-1	-1	-1	-1	-1	-2	-1.2	0.4
T	Effect of change in lifespan - maximum	0	1	0	1	1	2	0.8	0.8
L	Trained = Optimum								
L	Inexperienced = Minimum								
L	Experienced = Maximum								
L	Effect of change in lifespan - minimum	-4	-3	-1	-2	-13	-6	-4.8	4.4
L	Effect of change in lifespan - maximum	2	2	2	1	5	6	3.0	2.0
C	Trained = Optimum								
C	Inexperienced = Minimum								
C	Experienced = Maximum								
C	Effect of change in lifespan - minimum	-4	-3	-2	-2	-13	-4	-4.7	4.2
C	Effect of change in lifespan - maximum	2	2	3	1	5	4	2.8	1.5
	Travel Time								
T	*Haulage from the plant*								
T	Optimum	30	30	30	30	30	0	25.0	12.2
T	Minimum	30	30	5	60	30	0	25.8	21.5
T	Maximum	60	60	60	180	60	240	110.0	79.7
T	Effect of change in lifespan - minimum	-1	1	0	0	1	0	0.2	0.8
T	Effect of change in lifespan - maximum	0	-2	0	2	-3	-9	-2.0	3.8
L	*Time to offload (queing on site)*								
L	Optimum	10	10	0	0	10	0	5.0	5.5
L	Minimum	0	0	0	30	0	0	5.0	12.2
L	Maximum	60	60	60	120	60	240	100.0	72.7
L	Effect of change in lifespan - minimum	0	1	0	0	1	0	0.3	0.5
L	Effect of change in lifespan - maximum	-2	-2	-1	1	-3	-9	-2.7	3.4
C	*Waiting at paver for next load*								
C	Optimum	0	0	0	0	0	0	0.0	0.0
C	Minimum	0	0	0	30	0	0	5.0	12.2
C	Maximum	15	15	60	120	15		45.0	46.2
C	Effect of change in lifespan - minimum	0	1	0	0	1	0	0.3	0.5
C	Effect of change in lifespan - maximum	-1	-2	-1	4	-4	-9	-2.2	4.3
	Joints								
L	*Construction*								
L	Cold trimmed and painted = Optimum								
L	Cold and Unpainted = Minimum								
L	Hot Matched = Maximum								
L	Effect of change in lifespan - minimum	-2	-5	-2	-1	-8	-5	-3.8	2.6
L	Effect of change in lifespan - maximum	-2	0	2	1	0	5	1.0	2.4
L	*Number of joints*								
L	1 = Optimum								
L	0 = Minimum								
L	2 = Maximum								
L	Effect of change in lifespan - minimum	-1	-4	2	-1	0	0	-0.7	2.0
L	Effect of change in lifespan - maximum	-1	-8	-2	1	-5	0	-2.5	3.4
	Interlayer Bond								
L	*Amount*								
L	Optimum	400	400	400		400		400.0	0.0
L	No Bond = Minimum								
L	Maximum	500	500	500		600			
L	Effect of change in lifespan - minimum	-1	-1	-1	-1	-3	-2	-1.5	0.8
L	Effect of change in lifespan - maximum	0	2	1	2	3	-2	1.0	1.8

Slovenia summary response SMA8: Appendix C

Surface Course Type (Based on EN 13108)

SMA8PmB 80/65

		Researcher	Contractor/Asphalt Producer	Quality Control/ Contractor	Material Supplier	Supervising Engineer	Consultant/Supervising Eng	Analysis: Average	Analysis: Standard Deviation
	Expected Lifespan of the material (years)	15	10	20	15	15	18	15.5	3.4
	Maximum lifespan of chosen material (years)	20	15	35	20	18	25	22.2	7.1
	Minimum lifespan of chosen material (years)	12	8	10	12	12	10	10.7	1.6
	Temperature of Material								
T	Optimum	165	165	165	165	175	165	166.7	4.1
T	Minimum	155	155	155	155	155	155	155.0	0.0
T	Maximum	185	185	185	185	185	185	185.0	0.0
T	Effect of change in lifespan - minimum	-1.5	-0.8	-3	-1.5	-0.8	-4	-1.9	1.3
T	Effect of change in lifespan - maximum	-4.5	-2.5	-3	-4.5	-0.8	-4	-3.2	1.4
L	Optimum	165	165	165	165	170	165	165.8	2.0
L	Minimum	150	150	150	150	150	150	150.0	0.0
L	Maximum	180	180	180	180	185	180	180.8	2.0
L	Effect of change in lifespan - minimum	-3	-1.5	-3	-3	-0.8	-5	-2.7	1.5
L	Effect of change in lifespan - maximum	-4.5	-2.5	-3	-4.5	-0.8	-4	-3.2	1.4
C	Optimum	165	165	165	165	165	165	165.0	0.0
C	Minimum	145	145	145	145	145	145	145.0	0.0
C	Maximum	185	185	185	185	185	185	185.0	0.0
C	Effect of change in lifespan - minimum	-6	-1.5	-3	-3	-1.5	-5	-3.3	1.8
C	Effect of change in lifespan - maximum	-1.5	-2.5	-3	-4.5	-0.8	-4	-2.7	1.4
	Weather								
T	*Ambient temperature ºC*								
T	Optimum	25	25	25	25	25	25	25.0	0.0
T	Minimum	3	3	3	3	3	3	3.0	0.0
T	Maximum	36	36	36	36	36	36	36.0	0.0
T	Effect of change in lifespan - minimum	-6	-1.5	-2	-1.5	0	-5	-2.7	2.3
T	Effect of change in lifespan - maximum	0	0	0	0	0	2	0.3	0.8
L	*Wind Speed (km/h)*								
L	Optimum	0	0	0	0	0	0	0.0	0.0
L	Minimum	0	0	0	0	0	0	0.0	0.0
L	Maximum	50	50	50	50	50	50	50.0	0.0
L	Effect of change in lifespan - minimum	0	0	0	0	-0.8	0	-0.1	0.3
L	Effect of change in lifespan - maximum	-3	-2	-1	-3	-1.5	-4	-2.4	1.1
L	*Ambient temperature ºC*								
L	Optimum	25	25	25	25	25	25	25.0	0.0
L	Minimum	3	3	3	3	3	3	3.0	0.0
L	Maximum	36	36	36	36	36	36	36.0	0.0
L	Effect of change in lifespan - minimum	-3	-0.5	-2	-0.8	-0.8	0	-1.2	1.1
L	Effect of change in lifespan - maximum	0	-1	0	-1.5	-1.5	-5	-1.5	1.8
L	*Rainfall*								
L	No = Optimum	0	0	0				0.0	0.0
L	No = Minimum	0	0	0				0.0	0.0
L	Yes = Maximum	0	0	0				0.0	0.0
L	Effect of change in lifespan - minimum	0	0	0	0	0	0	0.0	0.0
L	Effect of change in lifespan - maximum	-7.5	-3	-4	-4.5	-1.5	-6	-4.4	2.1
C	*Wind Speed (km/h)*								
C	Optimum	0	0	0	0	0	5	0.8	2.0
C	Minimum	0	0	0	0	0	0	0.0	0.0
C	Maximum	50	50	50	50	50	40	48.3	4.1
C	Effect of change in lifespan - minimum	0	0	0	0	0	-5	-0.8	2.0
C	Effect of change in lifespan - maximum	-4.5	-3	-2	-3	-3	2	-2.3	2.2
C	*Ambient temperature ºC*								
C	Optimum	25	25	25	25	25	20	24.2	2.0
C	Minimum	3	3	3	3	3	9	4.0	2.4
C	Maximum	36	36	36	36	26	40	35.0	4.7
C	Effect of change in lifespan - minimum	-3	-2	-2	-3	-0.8	-5	-2.6	1.4
C	Effect of change in lifespan - maximum	0	0	0	0	-0.8	2	0.2	0.9
C	*Rainfall*								
C	No = Optimum	0	0	0				0.0	0.0
C	No = Minimum	0	0	0				0.0	0.0
C	Yes = Maximum	0	0	0				0.0	0.0
C	Effect of change in lifespan - minimum	0	0	0	0	0	3	0.5	1.2
C	Effect of change in lifespan - maximum	-3	-2	-4	-3	-1.5	0	-2.3	1.4
	Compaction								
C	*Void Content (%)*								
C	Optimum	4.5	4.5	4.5	4.5%	4.5%	4.5%	2.3	2.4
C	Minimum	1.5	1.5	1.5	1.5%	1.5%	1.5%	0.8	0.8
C	Maximum	7.5	7.5	7.5	7.5%	7.5%	7.5%	3.8	4.1
C	Effect of change in lifespan - minimum	-3	0	-1	0	-0.8	0	-0.8	1.2
C	Effect of change in lifespan - maximum	-4	-0.5	-5	-0.8	-0.8	-1	-2.0	2.0
C	*Number of Roller Passes*								
C	Optimum	6	6	6	6	6	6	6.0	0.0
C	Minimum	4	4	4	4	3	4	3.8	0.4
C	Maximum	10	10	10	10	10	10	10.0	0.0
C	Effect of change in lifespan - minimum	-1.5	-1.5	-2	-1.5	-1.5	-1	-1.5	0.3
C	Effect of change in lifespan - maximum	-0.8	-1	0	-0.8	-0.8	-1	-0.7	0.4
	Equipment								
T	Thermal Insulation = Optimum								
T	No Insulation = Minimum								

T	Temperature Coniditioned = Maximum								
T	Effect of change in lifespan - minimum	-3	-1.5	-2	-3	-1.5	-7	-3.0	2.1
T	Effect of change in lifespan - maximum	1.5	0.5	1	1.5	0.8	3	1.4	0.9
L	Commonly Used = Optimum								
L	No Vibratory Screed = Minimum								
L	Intelligent paver (gps with feedback) = Maximum								
L	Effect of change in lifespan - minimum	-1.5	-1	-3	-1.5	-3	-7	-2.8	2.2
L	Effect of change in lifespan - maximum	1.5	1	1	1.5	1.5	4	1.8	1.1
C	Commonly Used = Optimum								
C	Lightweight Roller = Minimum								
C	Intelligent Roller with feedback = Maximum								
C	Effect of change in lifespan - minimum	-7.5	-2	-3	-7.5	-1.5	-5	-4.4	2.7
C	Effect of change in lifespan - maximum	1.5	1	1	1.5	1.5	4	1.8	1.1
	Workmanship								
T	Trained = Optimum								
T	Inexperienced = Minimum								
T	Experienced = Maximum								
T	Effect of change in lifespan - minimum	-0.8	-1	-1	-0.8	-0.8	-1	-0.9	0.1
T	Effect of change in lifespan - maximum	0.8	0.5	0	0.8	1.5	1	0.8	0.5
L	Trained = Optimum								
L	Inexperienced = Minimum								
L	Experienced = Maximum								
L	Effect of change in lifespan - minimum	-3	-1	-4	-3	-3	-9	-3.8	2.7
L	Effect of change in lifespan - maximum	1.5	0.5	2	1.5	1.5	4	1.8	1.2
C	Trained = Optimum								
C	Inexperienced = Minimum								
C	Experienced = Maximum								
C	Effect of change in lifespan - minimum	-3	-1	-4	-3	-3	-9	-3.8	2.7
C	Effect of change in lifespan - maximum	1.5	0.5	2	1.5	1.5	4	1.8	1.2
	Travel Time								
T	*Haulage from the plant*								
T	Optimum	30	30	30	30	60	30	35.0	12.2
T	Minimum	30	30	30	30	60	30	35.0	12.2
T	Maximum	60	60	60	60	120	60	70.0	24.5
T	Effect of change in lifespan - minimum	0.8	2	0	0.8	0	1	0.8	0.7
T	Effect of change in lifespan - maximum	-1.5	-1	-2	-1.5	3	-2	-0.8	1.9
L	*Time to offload (queing on site)*								
L	Optimum	10	10	10	10	15	10	10.8	2.0
L	Minimum	0	0	0	0	15	0	2.5	6.1
L	Maximum	60	60	60	60	60	60	60.0	0.0
L	Effect of change in lifespan - minimum	0.8	2	0	0.8	0	1	0.8	0.7
L	Effect of change in lifespan - maximum	-1.5	-1	-2	-1.5	1.5	-2	-1.1	1.3
C	*Waiting at paver for next load*								
C	Optimum	0	0	0	0	0	0	0.0	0.0
C	Minimum	0	0	0	0	0	0	0.0	0.0
C	Maximum	15	15	15	15	15	15	15.0	0.0
C	Effect of change in lifespan - minimum	0.8	2	0	0.8	0	1	0.8	0.7
C	Effect of change in lifespan - maximum	-2.3	-1	-1	-2.3	4.5	-3	-0.9	2.7
	Joints								
L	*Construction*								
L	Cold trimmed and painted = Optimum								
L	Cold and Unpainted = Minimum								
L	Hot Matched = Maximum								
L	Effect of change in lifespan - minimum	-4.5	-2	-2	-4.5	-1.5	-5	-3.3	1.6
L	Effect of change in lifespan - maximum	0	0	-2	0	1.5	0	-0.1	1.1
L	*Number of joints*								
L	1 = Optimum								
L	0 = Minimum								
L	2 = Maximum								
L	Effect of change in lifespan - minimum	-3.8	-4	-1	-3.8	-1.5	0	-2.4	1.7
L	Effect of change in lifespan - maximum	-7.5	-5	-1	-7.5	1.5	-4	-3.9	3.6
	Interlayer Bond								
L	*Amount*								
L	Optimum	400	400	400	400	400	400		
L	No Bond = Minimum	300	300	300					
L	Maximum	500	500	500	500	500	600		
L	Effect of change in lifespan - minimum	-0.8	-1	-1	-0.8	-0.8	-2	-1.1	0.5
L	Effect of change in lifespan - maximum	2.3	2	0	2.3	2.3	2	1.8	0.9

Appendix D: Industry questionnaire – summary results

		UK Analysis HRA 35/14 F Surf 40/60		Netherlands Analysis ZOAB+		Slovenia Analysis SMA 8		Slovenia Analysis AC 11	
		Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation	Average	Standard Deviation
Expected Lifespan of the material (years)		19.2	4.2	13.3	1.2	15.5	3.4	17.0	5.7
Maximum lifespan of chosen material (years)		25.2	6.3	18.7	2.3	22.2	7.1	26.7	8.8
Minimum lifespan of chosen material (years)		11.4	3.7	7.3	3.8	10.7	1.6	11.7	5.2
Temperature of Material									
T	Effect of change in lifespan - minimum	-2.1	2.1	-0.2	1.9	-1.9	1.3	-2.3	1.5
T	Effect of change in lifespan - maximum	-2.8	5.0	-2.5	1.3	-3.2	1.4	-3.0	1.8
L	Effect of change in lifespan - minimum	-3.6	2.0	-1.0	1.0	-2.7	1.5	-3.0	2.6
L	Effect of change in lifespan - maximum	-1.2	2.9	-0.7	3.1	-3.2	1.4	-2.7	2.3
C	Effect of change in lifespan - minimum	-3.5	2.1	-2.3	2.5	-3.3	1.8	-3.5	2.6
C	Effect of change in lifespan - maximum	-0.1	2.4	-0.7	3.1	-2.7	1.4	-2.5	2.7
Weather									
Ambient temperature ºC									
T	Effect of change in lifespan - minimum	-4.6	4.2	-2.0	2.6	-2.7	2.3	-3.0	2.8
T	Effect of change in lifespan - maximum	0.0	0.0	0.7	1.2	0.3	0.8	0.5	1.2
Wind Speed (km/h)									
L	Effect of change in lifespan - minimum	0.0	0.0	1.0	1.0	-0.1	0.3	-0.2	0.4
L	Effect of change in lifespan - maximum	-5.8	4.0	-2.0	2.6	-2.4	1.1	-3.0	1.8
Ambient temperature ºC									
L	Effect of change in lifespan - minimum	-4.7	4.0	-1.7	2.9	-1.2	1.1	-1.7	1.4
L	Effect of change in lifespan - maximum	0.0	0.0	0.7	1.2	-1.5	1.8	-1.7	3.1
Rainfall									
L	Effect of change in lifespan - minimum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
L	Effect of change in lifespan - maximum	-4.9	4.5	0.0	0.0	-4.4	2.1	-4.7	2.9
Wind Speed (km/h)									
C	Effect of change in lifespan - minimum	0.0	0.0	1.0	1.0	-0.8	2.0	-1.3	3.3
C	Effect of change in lifespan - maximum	-6.3	4.2	-2.7	2.5	-2.3	2.2	-1.8	2.6
Ambient temperature ºC									
C	Effect of change in lifespan - minimum	-5.0	3.9	-3.0	3.6	-2.6	1.4	-3.0	2.8
C	Effect of change in lifespan - maximum	0.0	0.0	-0.3	2.5	0.2	0.9	-0.2	2.2
Rainfall									
C	Effect of change in lifespan - minimum	0.0	0.0	0.0	0.0	0.5	1.2	0.7	1.6
C	Effect of change in lifespan - maximum	-5.8	4.7	-1.7	2.1	-2.3	1.4	-3.3	2.8
Compaction									
Void Content (%)									
C	Effect of change in lifespan - minimum	-1.4	2.7	1.3	2.9	-0.8	1.2	-0.3	1.4
C	Effect of change in lifespan - maximum	-3.7	5.1	-1.3	3.1	-2.0	2.0	-2.8	3.0
Number of Roller Passes									
C	Effect of change in lifespan - minimum	-2.5	3.5	-2.0	2.0	-1.5	0.3	-2.2	2.5
C	Effect of change in lifespan - maximum	-1.5	2.1	0.3	2.5	-0.7	0.4	-0.3	0.8
Equipment									
T	Effect of change in lifespan - minimum	-4.6	2.2	-3.7	1.5	-3.0	2.1	-3.8	3.3
T	Effect of change in lifespan - maximum	-0.8	3.3	2.0	0.0	1.4	0.9	2.3	1.8
L	Effect of change in lifespan - minimum	-5.3	6.2	-1.3	2.3	-2.8	2.2	-4.3	3.7
L	Effect of change in lifespan - maximum	2.4	3.5	2.0	1.0	1.8	1.1	2.7	1.9
C	Effect of change in lifespan - minimum	-6.4	5.5	-2.0	2.0	-4.4	2.7	-4.7	2.9
C	Effect of change in lifespan - maximum	2.3	3.3	2.3	1.2	1.8	1.1	2.8	1.8
Workmanship									
T	Effect of change in lifespan - minimum	-2.9	4.8	-1.7	2.1	-0.9	0.1	-1.2	0.4
T	Effect of change in lifespan - maximum	0.0	0.0	0.7	1.2	0.8	0.5	0.8	0.8
L	Effect of change in lifespan - minimum	-5.8	10.7	-2.3	1.5	-3.8	2.7	-4.8	4.4
L	Effect of change in lifespan - maximum	0.7	1.6	2.0	0.0	1.8	1.2	3.0	2.0
C	Effect of change in lifespan - minimum	-5.5	10.5	-3.3	4.0	-3.8	2.7	-4.7	4.2
C	Effect of change in lifespan - maximum	0.7	1.6	2.3	0.6	1.8	1.2	2.8	1.5
Travel Time									
Haulage from the plant									
T	Effect of change in lifespan - minimum	0.0	0.0	1.0	1.0	0.8	0.7	0.2	0.8
T	Effect of change in lifespan - maximum	-3.9	4.5	-1.7	0.6	-0.8	1.9	-2.0	3.8
Time to offload (queing on site)									
L	Effect of change in lifespan - minimum	0.0	0.0	0.0	0.0	0.8	0.7	0.3	0.5
L	Effect of change in lifespan - maximum	-3.9	4.9	-1.0	1.0	-1.1	1.3	-2.7	3.4
Waiting at paver for next load									
C	Effect of change in lifespan - minimum	0.0	0.0	0.0	0.0	0.8	0.7	0.3	0.5
C	Effect of change in lifespan - maximum	-6.6	4.4	-2.0	2.0	-0.9	2.7	-2.2	4.3
Joints									
Construction									
L	Effect of change in lifespan - minimum	-11.4	14.9	-4.0	3.6	-3.3	1.6	-3.8	2.6
L	Effect of change in lifespan - maximum	7.9	17.2	2.7	0.6	-0.1	1.1	1.0	2.4
Number of joints									
L	Effect of change in lifespan - minimum	6.8	16.3	0.7	1.2	-2.4	1.7	-0.7	2.0
L	Effect of change in lifespan - maximum	-7.1	17.4	0.3	2.5	-3.9	3.6	-2.5	3.4
Interlayer Bond									
Amount									
L	Effect of change in lifespan - minimum	-13.2	18.2	-5.0	4.4	-1.1	0.5	-1.5	0.8
L	Effect of change in lifespan - maximum	6.0	17.8	1.3	1.5	1.8	0.9	1.0	1.8

Appendix E: WP1 Workshop Feedback, England

List of comments on the tool and the project in general following presentation at the Institute of Asphalt East Midland branch AGM, May 2015.

Comments;

- Overall the project is a good idea as little data available to quantify the effects of degradation factors on the lifespan and quality of materials.
- Unsure as to the affect the project will have in terms of implementation in tenders as there is already a move to implementing technology.
- Question raised as to whether this tool could serve as a surrogate for data measurement on site once verified and in use?
- Data needed for the questionnaire to produce the tool is difficult to provide with any accuracy, likely that the tool will need significant number of iterations to be suitable for use in industry.
- The tool has limited input from experts and opinion will vary greatly based on experience, needs more input from industry at an earlier stage.
- In addition, it is unlikely optimum will be a single point, it could be a range as very difficult to quantify due to the number of variables both within the scope of the project and out (traffic count to failure etc)
- Comments also made reference to the degradation factors, many are interlinked and cannot be treated in isolation, difficult to assess an individual components of the tool, would be nice to know that if temperature of material arriving on site if cool is linked through to influence compaction and laying.
- Whilst understood that manufacture was outside the scope of the project later models should be developed to incorporate this as it is really the starting point for quality and should not be overlooked/dismissed.

Appendix F: WP1 Workshop Feedback, Ireland

Notes taken during workshop feedback held 06/05/15 at an Institute of Asphalt Technology technical meeting. Approximately 20-30 people were in attendance. The presentation was followed by some fruitful discussion of the work completed to date and the tool. Some interesting discussion points which may be worth noting for the project are given below:

1. The question was raised as to whether someone in Ireland can use the tool for a material that was only examined in a different country, i.e., someone in Ireland examining Porous Asphalt, which was looked at in the Netherlands. Obviously, there are different environmental conditions in each country.

2. From the results of the questionnaire I had noted that inter-layer bond was an important parameter. It was noted by someone present that there were not many methods which examined bond coat. He also note that the trucks which spread bond coat have computerised systems for monitoring the rate of spread but that many of these trucks also have GPS trackers on board. He noted that it should be straight forward to link the two although he wasn't aware of it having been done by anyone. As we are only interested in ready to use methods, This will be noted in Deliverable 3.1.

3. The point was raised that the Consistend tool estimates the lifespan of the material without considering the expected traffic. It was noted that this is not realistic as the lifespan is dependant of the traffic on the road. It was indicated that our prediction is based on average traffic.

Appendix G: WP1 Workshop Feedback, Netherlands

24th June 2015

Attending:
Ron vd Aa (RWS)
Natasha Poeran (Boskalis)
Peter van Hinthem (Heijmans)
Rob Hofman (RWS, CEDR)
Sergei Miller (U Twente)
Jeroen van Stek (Reef)
Dave van Vliet (TNO)
Wim Courage (TNO)
Linda Abspoel (TNO)
Jos Wessels (TNO)

Copy to:
Berwich Stuer (Boskalis)
Mahesh Moenielal (Dibec)
Remy vd Beemt (BAM)
Gerbert van Bochove (Heijmans)
Cecile Giezen (TNO)
Project team CONSISTEND

Subject: CONSISTEND workshop experts

List of comments on the tool and the project as presented (version 9-the Netherlands).

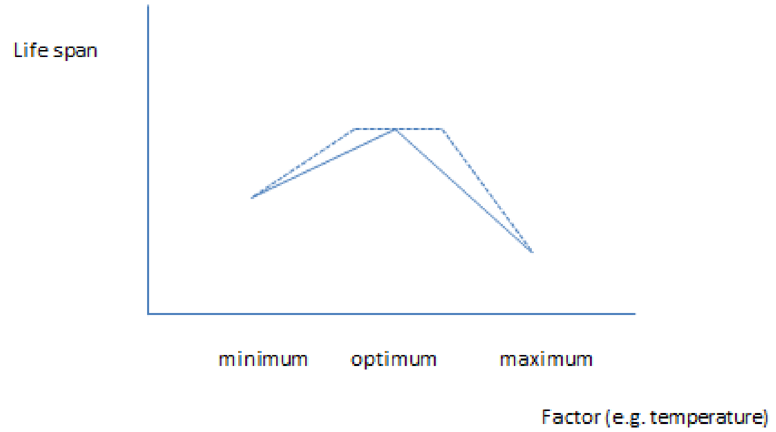
General remarks:

1. *Questions are not specific enough. Result will be a large variety of experts opinions because each expert will have his or her own perspective on the meaning of the question. E.g. temperature during transport: what exact moment is meant.*
2. *Some questions (degradation factors) are less important than others, how is this taken into account? No weighing factors are used. The importance of each factor depends on the expert opinion (estimated decrease of life time).*
3. *An important factor for the life span is the difference in temperature (not only the temperature itself). This is not in the model.*
4. *Differences in temperature and density (e.g. during stops) can cause weak points. The life span of a section is largely depending on the weakest spots.*

Specific remarks about the model:

1. *Every degradation factor has a specific influence on the life span. The model uses the assumption that a linear relation exist between the life span decrease and the degradation factor value (solid line). In reality the optimum value is not one value but a range of values (dotted line). This could be added to the model to make it more*

realistic.



2. *The model could be improved by a second expert opinion session, in which the questionnaire and the input parameters of the model will be made more specific and the answers of the expert can be discussed and tuned.*
3. *"Quality Control Measures" in the model (a heading in the input file) should be changed into "equipment", because the measures in the list are not (only) QC measures.*
4. *The input file should be clear about the influence of the QC measures (equipment). This will be done by adding information on the right side of each measure in the input file. Most equipment changes the uncertainty around one of the degradation factors.*
5. *Incorrect use of equipment will cause serious quality problems. Some equipment will influence more than one degradation factor. How is that taken into account (related to h).*
6. *Compaction: each mixture and circumstance will need its specific way of compaction. The model will have to be rather specific. The Dutch "ZOAB" can be seen as specific enough for the way this tool will be used.*
7. *It is possible to select the same kind of equipment twice (like a roller with IR, roller with GPS and roller with IR and GPS), it should be clear what input the model will use in these cases.*
8. *Void is a result of the process. It will be influenced by the other parameters. Rethink the position of this degradation factor, because it is a very important issue. Basically the most important performance factors for ravelling are: bonding, void and texture. All degradation factors should influence these factors.*
9. *Production is an important factor. The scope of the project is chosen to be Transport, Laying and Compaction. The original idea is that these factors are not yet well related to life span.*

Recommendations

1. *Use less parameters, make them more specific and go through the same process again in order to improve the outcome of the tool.*
2. *Involve provinces and cities in the process. This could be a very interesting tool for the Dutch market.*
3. *Experts are willing to cooperate in improving the model for the Dutch market.*
4. *For some degradation factors you should definitely see a change in life span when changing the value of this factor. Because of the number of factors taken into account in the model (24) and the 'damping' in the model, this is at the moment not the case.*

Next steps

1. *TNO will send minutes.*
2. *The questionnaires will be send to the experts again with the specific questions Linda added to the questionnaires. Experts will answer and send their recommendations to improve the questionnaire by skipping questions and adding other questions and comment on the existing questions. (ASAP)*
3. *TNO will propose a process to improve the questionnaire and the expert opinions as well as the model for the Dutch situation. E.g. by organising an expert session. (After summer)*
4. *TNO will organise a meeting to present the outcome of the project with the same group (added with provinces and cities) to discuss the results of the improved model. (December)*
5. *CEDR (Rob Hofman) and TNO will make sure that the model (tool) will be open for use for everyone involved.*