Recommendations to Scale up the Use of Intelligent Compaction Technology among Roller Operators in the Netherlands

Master Thesis Civil Engineering and Management

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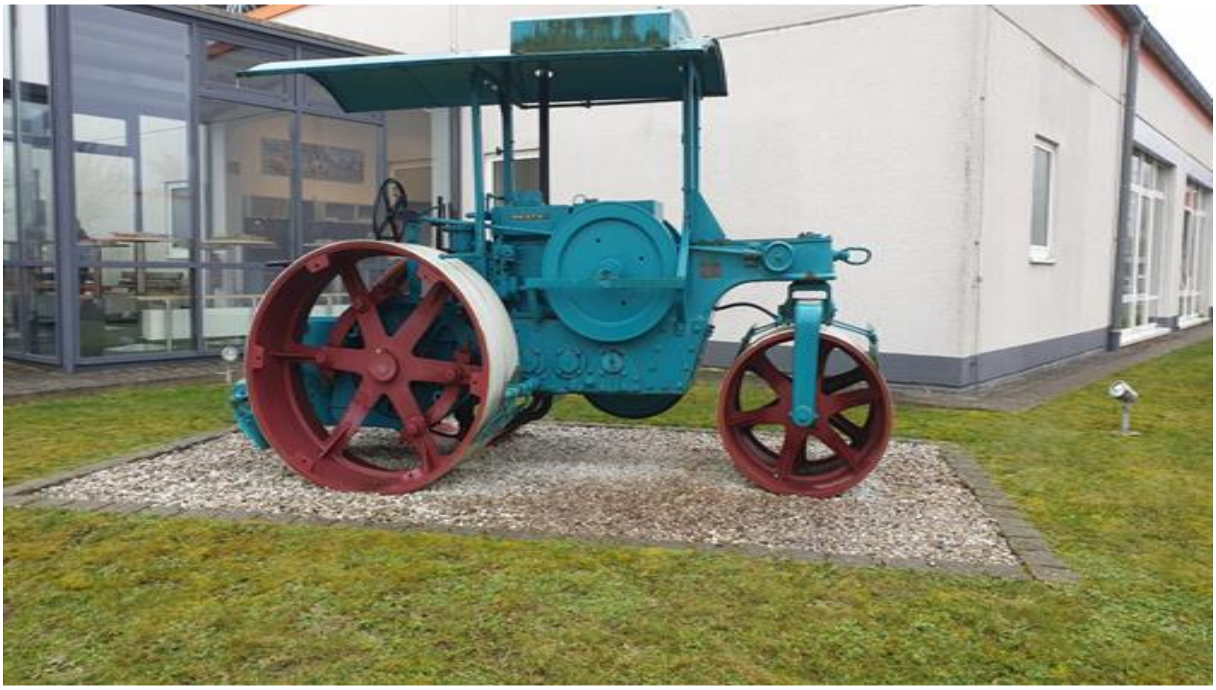

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Summary

The use of technology in daily life and various fields could be seen as a necessity nowadays. The use of technology could enhance work efficiency and provide large benefits for the users. However, the construction industry is a slow adopter of new technologies. The work process in the construction sector is still dependent on tradition and custom. This research thesis intends to focus on the use of one of the technologies in construction, specifically in road construction. This technology is the Intelligent Compaction (IC) which functions as an operation support system for roller operators in the compaction process of asphalt. The technology scans the road and provides roller operators with real-time temperature measurements. Additionally, the technology tracks the movement of the roller and, by assigning different colours to different numbers of passes, aids the roller operator in determining if the entire area is compacted as well as the number of passes.

Research has shown that roller operators occasionally tend to ignore intelligent compaction technology or even turn it off while they perform their tasks. The majority of pavement roller operators confess that they still hardly use IC technology during pavement. Further, no studies have been found that investigate the issue of lack of IC technology from roller operators' perspective in a structured scientific way. Therefore, this research thesis seeks to address the lack of use of IC technology from the operator's perspective and aims to offer recommendations that could scale up the use of this technology among roller operators in the Netherlands.

This study could investigate the barriers roller operators face in their daily use of IC technology by developing a research method that consists of technological and social criteria. Roller operators could give their points of view on the criteria of the research method by filling in a survey form. The survey was filled out by 43 roller operators from three construction companies. These companies are BAM, KWS and Heijmans. Further, a more in-depth investigation of the barriers, the reasons behind these barriers and the possible solutions for these barriers is accomplished through sixteen interviews with roller operators within the mentioned companies. The survey and interview results are validated internally by the roller operators and externally by validation experts.

The results of this study have shown that the lack of knowledge of roller operators about the support IC technology can offer, the lack of trust in the information provided by IC technology and the lack of communication between the management and roller operators on the data registered by IC technology are among the barriers causing less use of IC technology by roller operators. Moreover, the lack of training, the limitation of IC technology and the dis transparency of the management on the registered data by IC technology are among the barrier’s originators. The indicated barriers could be solved by multiple interventions such as comprehensive training provided to roller operators, using available technology advancement to solve the technology limitations, and promoting communication between the management and roller operators.

Furthermore, results have shown that roller operators are more dissatisfied with the social aspects than the technological aspects concerning the use of IC technology. This highlights the

fact that IC technology is not introduced to roller operators in a satisfactory manner. In addition, results have shown that young roller operators who have up to ten years of experience are more open to the use of IC technology in their daily work. This could be related to the fact that the younger generation is more familiar with using technology in daily life.

Solving technical issues, making the training obligatory for roller operators, and communicating the registered data by IC systems regularly with roller operators are among the recommendations that could scale up the use of IC technology by roller operators. Overall, improving the system's features and addressing operators' concerns could lead to higher acceptance and use of IC systems by roller operators.

Samenvatting

Het gebruik van technologie in het dagelijks leven en op verschillende terreinen kan tegenwoordig als noodzaak worden gezien. Het gebruik van technologie kan de werkefficiëntie verbeteren en grote voordelen voor de gebruikers opleveren. De bouwsector is echter een langzame adoptant van nieuwe technologieën. Het werkproces in de bouwsector is nog steeds afhankelijk van traditie en gewoonte. Deze onderzoek scriptie wil zich richten op het gebruik van een van de technologieën in de bouw, met name in de wegenbouw. Deze technologie is de Intelligent Verdichting, die functioneert als een operationeel ondersteunend systeem voor walsmachinisten bij het verdichtingsproces van asfalt. De technologie scant de weg en biedt walsmachinisten realtime temperatuurmetingen. Bovendien registreert de technologie de beweging van de wals en helpt de walsmachinist, door verschillende kleuren toe te wijzen aan verschillende aantallen gangen, bij het bepalen of het hele gebied verdicht is, evenals het aantal gangen.

Uit onderzoek is gebleken dat walsmachinisten af en toe de neiging hebben om intelligente verdichtingstechnologie te negeren of deze zelfs uit te schakelen terwijl zij hun taken uitvoeren. De meerderheid van de walsmachinistengeeft toe dat zij bij het bestraten nog steeds nauwelijks gebruik maken van IC-technologie. Verder zijn er geen studies gevonden die het probleem van het gebrek aan IC-technologie vanuit het perspectief van walsmachinisten op een gestructureerde wetenschappelijke manier onderzoeken. Daarom probeert dit proefschrift het gebrek aan gebruik van IC-technologie vanuit het perspectief van de operator aan te pakken en aanbevelingen te doen die het gebruik van deze technologie onder walsmachinisten in Nederland kunnen opschalen.

Deze studie zou de barrières kunnen onderzoeken waarmee walsmachinisten worden geconfronteerd bij hun dagelijks gebruik van IC-technologie door een onderzoeksmethode te ontwikkelen dat bestaat uit technologische en sociale criteria. Walsmachinisten konden hun mening geven over de criteria van de methode door een enquêteformulier in te vullen. De enquête wordt ingevuld door 43 walsmachinisten van drie bouwbedrijven. Deze bedrijven zijn BAM, KWS en Heijmans. Verder wordt er diepgaander onderzoek gedaan naar de barrières, de redenen achter deze barrières en de mogelijke oplossingen voor deze barrières door middel van 16 interviews met walsmachinisten binnen de genoemde bedrijven. De enquête- en interviewresultaten worden intern gevalideerd door de walsmachinisten en extern door validatie-experts.

Uit de resultaten van dit onderzoek is gebleken dat het gebrek aan kennis bij walsmachinisten over de ondersteuning die IC-technologie kan bieden, het gebrek aan vertrouwen in de informatie die IC-technologie biedt en het gebrek aan communicatie tussen het management en walsmachinisten over de door IC geregistreerde gegevens technologie behoren tot de barrières die ervoor zorgen dat er minder gebruik wordt gemaakt van IC-technologie door walsmachinisten. Bovendien behoren het gebrek aan tarining, de beperking van IC-technologie en de ondoorzichtigheid van het beheer van de geregistreerde gegevens door IC-technologie tot de oorzaken van barrières. De aangegeven barrières zouden kunnen worden opgelost door meerdere interventies, zoals een uitgebreide training voor walsmachinisten, het gebruik van beschikbare technologische vooruitgang om de technologische beperkingen

op te lossen en het bevorderen van de communicatie tussen het management en de walsmachinisten.

Bovendien blijkt uit de resultaten dat walsmachinisten ontevredener zijn over de sociale aspecten dan over de technologische aspecten in relatie tot het gebruik van IC-technologie. Dit onderstreept het feit dat de IC-technologie niet op een goede manier wordt geïntroduceerd naar walsmachinisten. Bovendien hebben de resultaten aangetoond dat jonge walsmachinisten met tot wel tien jaar ervaring meer openstaan voor het gebruik van IC-technologie in hun dagelijkse werk. Dit zou te maken kunnen hebben met het feit dat de jongere generatie meer vertrouwd is met het gebruik van technologie in het dagelijks leven.

Het oplossen van technische problemen, het verplicht stellen van de training voor walsmachinisten en het regelmatig communiceren van de geregistreerde gegevens door IC-systemen met walsmachinisten behoren tot de aanbevelingen die het gebruik van IC-technologie door walsmachinisten zouden kunnen opschalen. Over het geheel genomen zou het verbeteren van de functies van het systeem en het wegnemen van de zorgen van operators kunnen leiden tot een grotere acceptatie en gebruik van IC-systemen door walsmachinisten.

Acronyms and Abbreviations

IC	Intelligent Compaction
OSS	Operation Support System
HCQ	HAMM Compaction Quality
SD	Smart Doc.
TCC	Trimble Compaction Control
HMA	Hot Mix Asphalt
GPS	Global Positioning System
ICMV	Intelligent Compaction Measurement Value
IDT	Innovation Diffusion Theory
SCT	Social Cognitive Theory
MM	Motivation Model
TAM	Technology Acceptance Model
UTAUT	Unified Theory of Acceptance and Use of Technology
NASA-TLX	National Aeronautics and Space Administration Task Load Index
SUS	System Usability Scale
DOTs	Departments of Transportation

1. Introduction

The use of digital technologies nowadays is popular among individuals and various industries. These technologies simplify tasks, and increase productivity and efficiency (Banco Santander, 2023). While multiple technologies are currently in use in the construction sector, the construction industry has long been viewed as a slow adopter of new processes and technologies (Wang et al., 2020). In fact, the construction sector can be considered one of the least digitized sectors (Agarwal et al., 2016). The sector has not yet favoured new digital technologies even though there are huge long-term benefits that these technologies can offer (Agarwal et al., 2016). Many of the challenges facing the construction sector can be addressed by developed and tested technologies, but the acceptance and usage rates of these technologies are still low (Subramanya et al., 2022).

Focusing on the road construction sector, this issue is present in research where the work processes in road construction are still seen to be dependent on tradition and custom (Dalence, 2021). Multiple technologies have been developed to support workers in this sector in accomplishing their duties more efficiently. One of these technologies is Intelligent Compaction (IC) which is utilized in the rollers used for road construction.

During the pavement process, trucks deliver Hot Mix Asphalt (HMA) for asphalt roads, and a paver follows the truck slowly to spread the asphalt at the right depth. To achieve optimal compaction, a roller operates behind the paver (Deere & Company, 2022). Intelligent Compaction serves as an operational support system (OSS) for roller operators during the asphalt compaction process. This technology scans the road and provides real-time temperature measurements to roller operators. Additionally, it tracks the roller's movement and uses different colours to indicate the number of passes, helping the roller operator determine if the entire area is compacted and the number of passes required. The use of IC systems offers a more effective approach to assist roller operators in avoiding over-compaction and under-compaction by continuously providing information that enables the machine operator to complete the ideal number of roller passes (Horan et al., 2012).

Research has revealed that machine operators in road construction occasionally tend to ignore digital systems or even deactivate them while performing their tasks (Makarov, 2017). The majority of pavement roller operators admit that they rarely use IC technology during pavement (Bijleveld, 2015). In this context, no studies have been conducted to investigate the issue of the lack of IC technology usage from the perspective of roller operators in a structured scientific manner.

To summarize, the construction industry is seen as a slow adopter of technologies which makes most processes in this sector based on tradition and custom. Focusing on a technology used in road construction called intelligent compaction, it becomes clear that roller operators, who are the end-users of this technology, tend not to utilize IC technology and may even ignore the feedback they receive from this technology. The challenges contributing to the lack of IC technology usage in road construction are associated with roller operators since they are the primary end-users of this technology. However, no studies have attempted to investigate the issue of underutilization from the perspective of roller operators. Therefore, this study aims to comprehensively examine the lack of IC technology use among roller operators in a scientifically structured manner, focusing on the end-user experience.

Based on the information presented above, the problem statement is formulated as follows:

“There is a lack of IC technology use by roller operators and previous investigations lack a focus on their user experience.”

1.1 Research Objective

Based on the issues outlined in the problem context, the objective is formulated as follows:

“To develop recommendations that could scale up the use of IC technology among roller operators in the Netherlands.”

1.2 Research Questions

The research question is formulated in line with the research objective as follows:

- ❖ How can the use of intelligent compaction technology be expanded among roller operators in the Netherlands?

To answer the research question, the following three preliminary questions must be answered first.

1. What are the difficulties associated with the lack of use of IC systems among some roller operators?

2. What are the reasons that cause these difficulties?

3. How can the difficulties be addressed to expand the use of IC systems among roller operators?

1.3 Research Scope

This research is centred on the utilization of IC technology in the Netherlands, specifically focusing on asphalt pavement compaction. Additionally, the research involved three types of IC systems: HAMM Compaction Quality (HCQ), Smart Doc (SD), and Trimble Compaction Control (TCC). Furthermore, the research was primarily conducted within BAM Infra Nederland in collaboration with KWS and Heijmans.

1.4 Reading Guide

This document is structured as follows. The research methodology is illustrated and visually represented in chapter two. In chapter three, a literature review is conducted to gain knowledge about the pavement compaction process, IC technology, technology adoption in construction, and assessment models. Chapter four involves the analysis of data, with results presented therein. The results are discussed in chapter five. In chapter six, conclusions are drawn based on the research findings. Finally, the recommendations are formulated in chapter seven.

2. Research Methodology

In this chapter, the steps that have been taken to reach the research objective are explained. The research is intended to be exploratory research that uses survey and interview methodologies to address research questions and achieve the objective of the research. This decision was made because the exploratory approach aims to look at a problem that we do not fully understand or that shows a certain level of complexity (Laws & McLeod, 2006). This is in line with the problem context of this research. The methodology of this study is divided into four key categories. These include the theoretical components, data collection, data analysis and results validation. These categories are explained in the following sub-sections.

2.1 Theory

This part includes a literature review on multiple components needed by the researcher to build sufficient theoretical knowledge to develop the research method and become familiar with the elements of the systems that the research focuses on. This involves a literature review on the pavement compaction process, the development of IC technology and its components, the challenges associated with the use of this technology and the IC systems investigated in this research. Besides, a literature review on technology adoption in construction and the available models that can be used to assess the use of IC systems has been conducted.

Based on the literature review, a research method to investigate the use of IC systems among roller operators is developed. The research method consists of multiple criteria that need to be measured to detect the difficulties facing roller operators concerning the use of IC technology. Therefore, each criterion is linked to a question based on the literature review as well. The developed research method can be seen in Table 2. A more detailed explanation of the developed research method including the criteria and linked questions can be found in the literature review in section 3.3.3.

2.2 Data Collection

Data for this study is collected in two manners. These are surveys and interviews. Starting with the survey data, the questions linked to the criteria established in the research method are used in this survey. The survey list can be seen in Table 2. Each question is measured by a five-point Likert scale (Alston et al., 2002). The survey list is spread to three big construction companies which are BAM, KWS and Heijmans.

The survey is followed by semi-structured interviews. A protocol for semi-structured interviews is prepared. The protocol can be seen in Appendix B. The purpose of semi-structured interviews is to provide the interviewees with a safe environment wherein they feel at ease reflecting on their personal experiences while also offering the researcher a comprehensive insight into a specific subject of interest (Sadler, 2017). This necessitates the researcher to allow for exchange with the interviewee, which is accomplished by open-ended questions and, if necessary, improvised follow-up questions (Sadler, 2017).

The interviews were held with ten roller operators from BAM, six roller operators from KWS and one roller operator from Heijmans. Since the type of interview is semi-structured, the questions need to be open to a specific extent to collect the most valuable ideas from the interviewees. The developed questions can be found in Table C in Appendix B. The interview questions are a more in-depth investigation of survey questions. In other words, the survey was held to identify the obstacles roller operators face while the interviews took place to identify the reasons behind these obstacles and attempt to find solutions for these problems. Therefore, the results of the survey are used as background during the interviews. The interview protocol form can be seen in Appendix B.

2.3 Data Analysis

The survey results are analysed, and the difficulties associated with the use of IC technology are indicated. Descriptive statistics are used to illustrate the survey results since descriptive statistics describe the trends of the data and classify them (Marshall & Jonker, 2010). Furthermore, the survey results of different participated companies in the research are compared to check the statistical significance of the results using the independent t-test (Laerd Statistics, 2018).

The interviews' inputs have been analysed using Thematic Analysis. The thematic analysis process included the following stages (Braun & Clarke, 2006).

The first stage was to be familiarised with data. This stage included transcribing the interviews and reading through the interviews' transcriptions. The interview transcriptions are one by one read to be familiarised with the data. The data is cleaned by removing any irrelevant conversations in the interviews. Further, initial ideas are noted. The second stage was to generate initial codes.

The second stage involved initial coding for interesting content identified in the interviews. Further, the similar input type from each interview is clustered under the same code. This resulted in multiple groups of codes.

The third stage was to search for themes. The third stage aimed to gather all relevant codes under a potential theme by looking at similarities between codes.

The fourth stage was to review themes. In the fourth stage, the connection between the created codes and chosen themes has been guaranteed by implementing two levels of reviewing. Level one includes reviewing the extracted data that has been coded to check if they seem to make sense as a pattern. Level two includes the same procedure but regarding the entire data group to check if any themes were overlooked in earlier stages of coding. The fifth stage was defining and naming themes.

The fifth stage included refining and defining the themes presented. This stage involved analysing the data within these themes by identifying the interesting findings in these themes and indicating the story that each theme presents concerning research questions. As a part of the refinement, the identified themes are gathered under a main theme. The main theme in this case was the survey criteria. The relevant themes to a specific main theme (survey criteria) are clustered under this theme. This step also enabled a connection between the survey and interview results. At the end of this stage, names that give a comprehensive idea about each theme have been given to the themes.

The sixth stage was producing the report. The final stage included reporting the sub-themes under each main theme and connecting the thematic analysis results with the descriptive analysis results. This has been done by telling the story of each theme in relation to the research questions including data extracted from the interviews as evidence.

An example of the steps followed in the thematic analysis above can be seen in Table D in Appendix C. The information gained from the thematic analysis gives a comprehensive insight into the causes behind the difficulties roller operators face in their daily work. Further, the researcher used the interviews to collect suggestions from the roller operators' perspective on how the difficulties can they face be tackled.

2.4 Results Validation

Survey and interview results are internally and externally validated. Internally, the results are summarized and presented individually to four roller operators from BAM and three roller operators from KWS. These roller operators were the same roller operators interviewed before.

Externally, the results are validated using the Focus Group method (Jung & Ro, 2019). The results are discussed during two sessions for two hours each. The four individuals involved in the focus group interaction were experts in the road construction industry. More information on the involved experts can be seen in Table 1 below.

The input collected during the focus group interaction is analysed using Thematic Analysis as well. The output of these validation sessions is further connected with the survey and interview results in the results section.

Table 1 Experts involved in focus group validation

#	Job title
1	Roller operators' trainer at a Dutch College
2	Product manager of digital solutions at a machine supplier company
3	Asphalt/Equipment manager at a Dutch construction company
4	Head of the central asphalt lab at a Dutch construction company

2.5 Results Output

To answer the preliminary research questions and then the main research question, the following steps have been implemented.

First, the literature review is used to develop the research method and survey questions. The survey data is analysed and then validated. The outcome of this process is used to answer preliminary question one.

Second, the developed interview question is used to conduct interviews. The interview data is analysed and validated. The outcome of this process is used to answer preliminary questions two and three.

Finally, the survey and interview results are further analysed by reflecting on these results using various literature. Based on the knowledge gained from the results, validation and reflection, recommendations that could scale up the use of IC technology among roller operators are developed. In this manner, the main research question is answered, and the research objective is achieved. A representation of the research methodology can be seen in Figure 1 below.

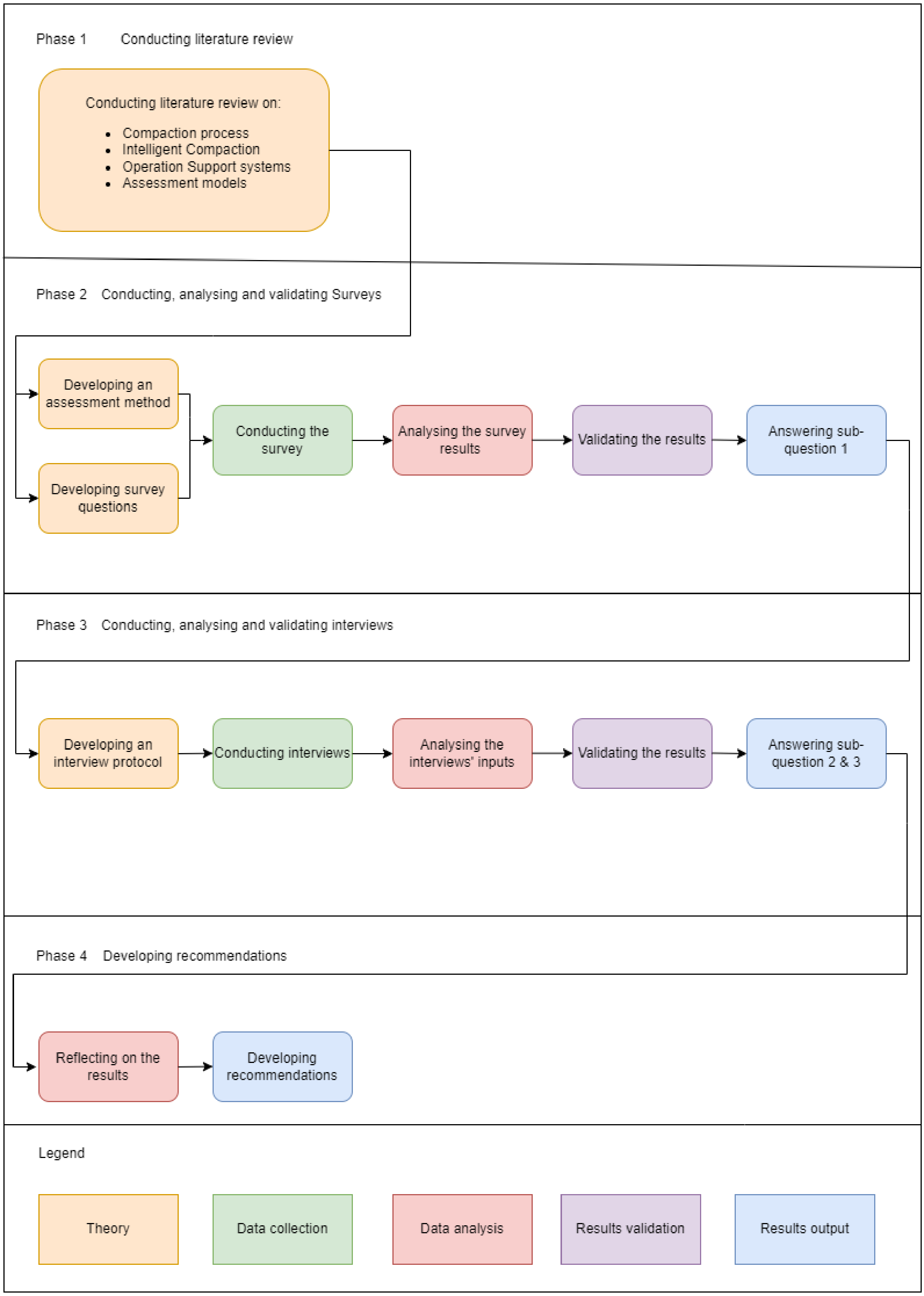

Figure 1 Research methodology

3. Literature Review

In this chapter, the pavement compaction process is researched to gain a deeper understanding of it. Additionally, IC technology, its components, types, and the challenges associated with this technology are explored. Furthermore, a literature review on technology adoption in construction and the available models that can be used to assess the utilization of IC systems is conducted.

3.1 Pavement Compaction Process

Asphalt pavement operation in Figure 2 starts with distributing the HMA brought by trucks from the asphalt plant using an asphalt spreading machine (asphalt paver). This machine has to spread asphalt with the proper width, height, and slope. This machine aims to spread asphalt in the appropriate width, height and slope. The asphalt is then compacted with a roller to obtain the required strength and density to handle the traffic load. Research indicates that the primary factor influencing the end-result quality of road construction is the compaction of the asphalt mixture (Simons, 2007).

Figure 2 Asphalt pavement operation (Freepick, n.d.)

The operation of compaction is important because it aims to decrease the volume of asphalt mixes and rise the density of these mixtures (Perko et al., 2000). The durability of asphalt pavements depends heavily on compaction (Kassem et al., 2015). Rutting, moisture damage, and rapid ageing are caused by inadequate compaction. The compaction of asphalt blends is affected by a number of variables, including the quantity of asphalt binder, aggregate gradation, aggregate properties, temperature, and roller sort (Perko et al., 2000). The temperature could be the most important factor in the compaction process. Roller operators need to compact the asphalt within the temperature window as can be seen in Figure 3. Temperature windows represent the temperature limits based on the cooling curve of asphalt mixes to avoid corrugations with high temperatures and damage with low temperatures (Vasenev et al., 2012).

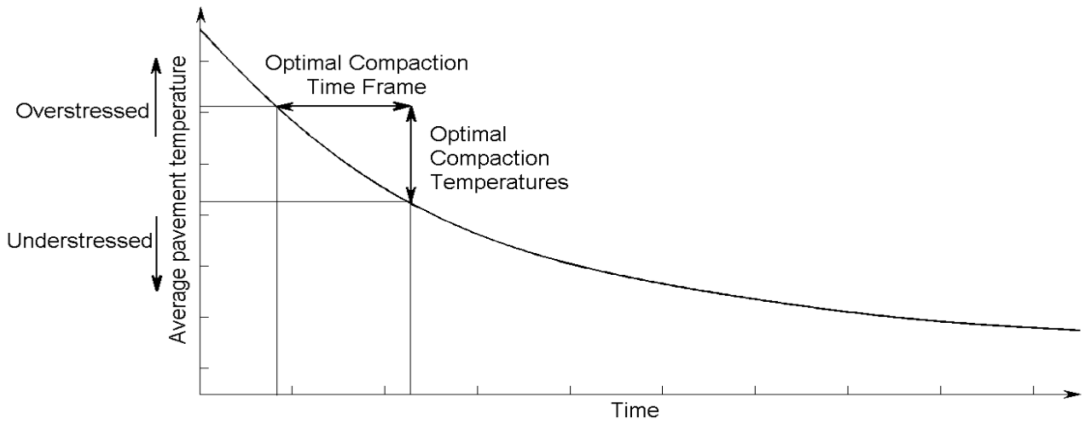

Figure 3 Cooling curve asphalt mixture and compaction window (Vasenev et al., 2012).

The concept of an optimal compaction grade for HMA mats is theoretically possible. According to Chadbourn et al., (1998), if the HMA surface is over-compacted, it loses its flexibility since there are not sufficient air gaps in it, whereas if the surface is under-compacted, it will not be sufficiently rigid. However, deciding when to begin and cease compaction operations during the "real world", is one of the major challenges in the asphalt construction process. It might be also challenging for operators to determine when the HMA mat has been sufficiently compacted (S. R. Miller et al., 2011).

Moreover, According to Vasenev et al., (2012), the final product may be negatively impacted if compaction is performed when the asphalt layer is cooler or warmer than a specific temperature. In reality, determining when to start and stop compacting is typically dependent on past experiences and an unclear understanding of the asphalt's temperature. The temperature of the asphalt is frequently inferred from indirect factors including surface colour. This kind of data collection is unreliable, particularly for procedures that take place at night. However, a number of road construction tasks must be completed at night in order to prevent high traffic hours, making temperature estimation even more challenging. The operational behaviour and, ultimately, the final road surface, could both be affected by uncertainties in temperature estimation.

Over the years, achieving the desired compaction level of asphalt has been reasonably accomplished through traditional compaction techniques (Hu, Shu, et al., 2017). However, there have been four significant shortcomings persisting in these traditional compaction techniques for an extended period (Horan et al., 2012).

The first shortcoming is the inability of the project team to receive real-time feedback from traditional compaction machinery. The second significant drawback of conventional compaction machinery is the ease with which over-compaction can occur, potentially reducing the previously achieved density with prior passes. Third, a limited number of spot tests are conducted, using either cores or nuclear instruments, and the conclusions drawn from these tests are used to determine the density grade of the entire pavement. Fourth, density measurements are performed only after compaction is completed. Consequently, it is often too late to take corrective action if it is discovered that the desired specification density was not achieved after compaction.

Furthermore, achieving a uniform roller pattern across the entire road is a challenging process because rollers are manually operated by roller operators (Hu, Shu, et al., 2017).

Overall, experience and trial and error are used to determine the proper compaction pattern, which is a costly and time-consuming operation (Kassem et al., 2012). The industry, primarily the suppliers of asphalting equipment, has developed advanced asphalt characteristics and process measuring technology to aid HMA paving operators in their paving efforts (Zambrano et al., 2006). One of these technologies is Intelligent Compaction. Intelligent Compaction technological advances are utilized to constantly track the field compaction of asphalt pavements (Commuri et al., 2011; MAUPIN, 2007).

3.2 Intelligent Compaction Technology

Intelligent compaction refers to a roller occupied with a Global Positioning System (GPS), accelerometer, temperature sensors and a display as can be seen in Figure 4. A roller without these pieces of equipment is a normal roller used in conventional compaction.

Uniform compaction is gained by implementing more force in the area where more compaction is needed and implementing less force in the area where less compaction is needed within the temperature window (Zhang et al., 2019). Obtaining such a goal is not a simple task with conventional compaction because it depends on the roller operator's expectation and experience in implementing the location and the amount of the force, setting roller speed and the number of passes. Intelligent compaction is an alternative way to achieve these goals (Zhang et al., 2019).

Intelligent compaction was introduced in the 1970s. The concept of Intelligent compaction refers to developed compaction progress with a roller supplied with an integrated measurement system provided with a highly precise GPS, accelerometer, temperature sensors and a colour screen where the movement of the roller is recorded constantly in a coloured map (Hu, Huang, et al., 2017). Following in 3.2.1 is an explanation of each part of the IC system.

IC is designed to help roller operators by providing them with real-time information. This information is the asphalt temperature represented in a color-coded map, the number of passes he made over the asphalt mat and the cumulative compaction effort which is the amount of energy applied to the asphalt mat. Roller operators could use this real-time information to adjust the rolling force, rolling location and their compaction behaviour in general to achieve the optimal compaction of asphalt.

In addition to the support that IC technology provides for roller operators, research has shown that the use of IC technology increases the uniformity of asphalt pavement and could result in cost savings by decreasing maintenance costs and longer lifespan of asphalt (Savan et al., 2016). The use of IC might solve the drawbacks of traditional compaction. The IC measurement value (ICMV) can be used as an indicator for determining the stiffness or rigidity of pavement to a particular thickness (A. Mooney, 2010).

3.2.1 The Components of Intelligent Compaction Technology

The IC system consists of multiple components. These are a global positioning system, accelerometer, temperature sensors and display. Each element is explained separately in the following sections.

3.2.1.1 Global Positioning System

The global positioning system is a widely used system to indicate the location with different accuracy based on the purpose that used for. The accuracy of the GPS used with the IC technology should be high to be acceptable in road construction(Kassem et al., 2015). The function of GPS in the IC process is to provide the location of the roller in real-time, the speed of the roller, the number of passes and the compaction path(Zhang et al., 2019). To grant high accuracy, some techniques are used within the GPS such as RTK which enables the GPS to provide an accuracy between 1-3 cm in the horizontal direction and 2-5 cm in the vertical direction(Liu et al., 2016).

3.2.1.2 Accelerometer

The accelerometer is a device to measure the acceleration during movement. It has multiple types and weights according to the purpose of use. The accelerometer is adopted in intelligent compaction. The accelerometer is located on the side of the roller drum to measure the vertical drum acceleration during the compaction process. It transfers these measurements at different times to frequency. This frequency is used to determine the Intelligent Compaction Measurement Value (ICMV) which is an index of ground stiffness(Liu et al., 2016).

3.2.1.3 Temperature Sensors

The temperature of asphalt is one of the most important factors in the pavement process (Hu, Shu, et al., 2017). To keep the driver of the roller informed about the temperature of the pavement, temperature sensors are installed on the roller. In that way, the driver of the roller could know when to start or stop the compaction process. Most of the used temperature sensors in rollers are infrared temperature sensors. These sensors are located in the front and back of the roller to be able to collect the temperature record in two directions of roller movement(Hu, Shu, et al., 2017).

3.2.1.4 Display

All the data gathered from GPS, Accelerometer and temperature sensors are collected and visualised on a screen in the cabinet of the roller operator. In this manner, the roller operator can control the compaction pattern according to the data that he receives to ensure the best quality of compaction. The dynamic temperature of asphalt is shown in the visualization for the roller driver. roller operator sees the compaction map and the temperature contour plot on the screen and based on these inputs he can adjust his compaction pattern and achieve the best compaction quality (Makarov et al., 2020).

3.2.2 The Working Mechanism of Intelligent Compaction Components

The intelligent compaction mechanism depends mainly on information exchange between the IC components. The Accelerometer registers continuously the interaction that happens between the roller and the ground by calculating the Intelligent Compaction Measurement Value (ICMV). ICMV represents an indicator of material stiffness for quality control. The GPS works on detecting the location of the roller and through this information, the number of passes plus the roller velocity can be derived. The temperature sensors record the temperature. The measurements of these components are correlated to the system on a screen located in the roller operator cabin (Liu et al., 2020).

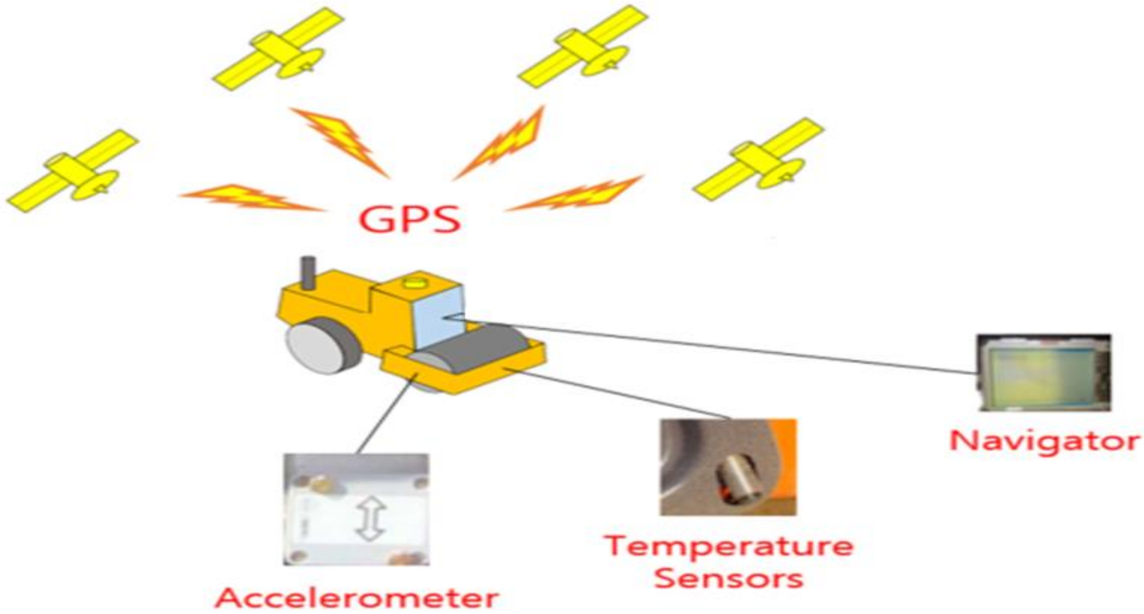

Figure 4 Intelligent Compaction System (Lee et al., 2022)

3.2.3 Types of Intelligent Compaction Systems

There are multiple types of IC systems. The three types of systems investigated in this research are explained below.

3.2.3.1 HAMM Compaction Quality

HAMM Compaction Quality (HCQ) is one of the most common OSSs. A variety of devices are included in HCQ that are intended to measure, monitor, record, and monitor compaction and the processes involved in it. One of these is the compaction meter, which calculates stiffness values, and the temperature meter, which gauges asphalt temperature. The display in the cabin of roller operators display these two data sets for the operator (HAMM, 2020).

Besides, HCQ is provided with a navigator. This regularly determines the location of the rollers using a GNSS receiver. The data is then shown on a display Computer with a touchscreen in the driver's cabin as a real-time "compaction map," which also provides multiple characteristics including the current speed, amplitude, and frequency (HAMM, 2020).

Moreover, the screen displays the various passes of the roller as well as the overall compaction process of other rollers since the rollers may also interact with each other via a Wi-Fi connection. The roller operator can therefore still see which parts were suitably compacted and which areas need another pass (HAMM, 2020). HCQ can be seen in Figure 5 below.

Figure 5 HAMM Compaction Quality (HAMM, 2019)

3.2.3.2 Smart Doc.

Smart Doc. (SD) is the new version of the IC technology developed by HAMM. SD has an addition of a free Android app that provides continuous compaction measurements and recording in asphalt paving (HAMM, 2022). Before proceeding with the compaction, the operator can make a project in the form of a construction segment with details on the layers and substance.

The most crucial compaction values are then recorded by the app throughout compaction. This includes the frequency, amplitude, HMV compaction value, number of double passes, actual working velocity, amplitude, frequency, and asphalt heat. This information is combined with the location information that was obtained via a smartphone or smart transmitter and displayed for roller operators on a tablet (HAMM, 2022).

SD provides an option to specify target values, such as the stiffness to be reached or the number of passes to be finished before starting the compaction process. Moreover, the driver can designate and control different layers. A pdf compaction report is created once the compaction is finished (HAMM, 2022). SD can be seen in Figure 6 below.

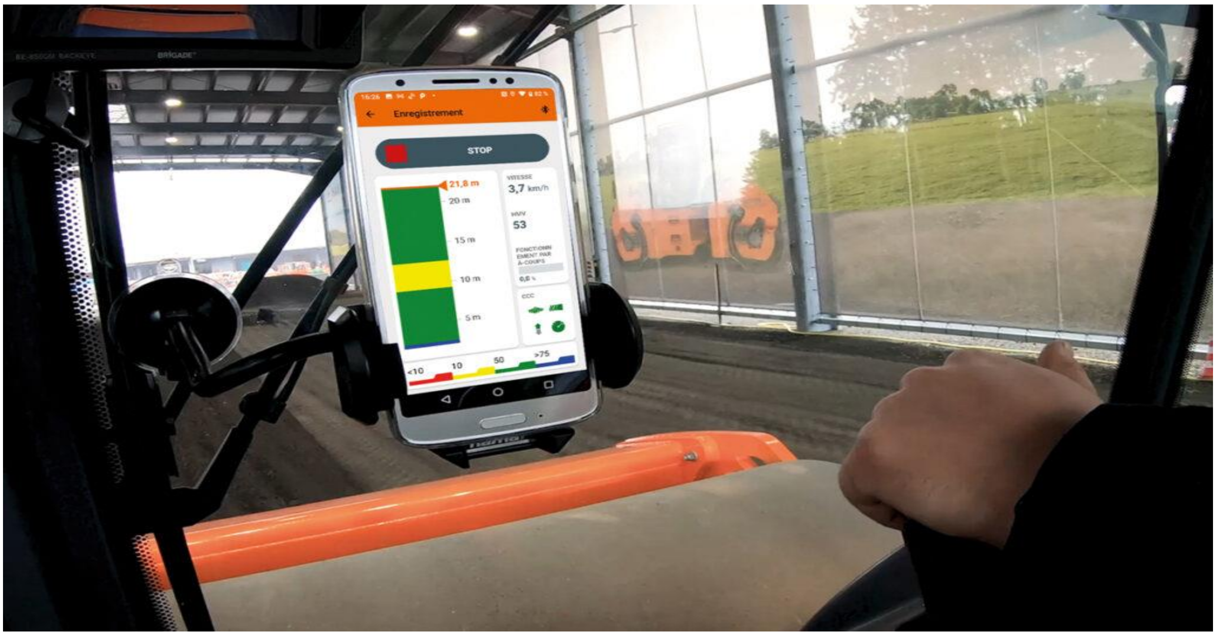

Figure 6 Smart Doc. (BOUWMAT, 2021)

3.2.3.3 Trimble Compaction Control

Similar to HCQ and SD, Trimble Compaction Control (TCC) offers real-time visualization and mapping of compaction measures, as well as on-machine documentation of compaction outcomes (Trimble Heavy Industry, 2021).

The system displays compaction progress, pass numbers, and mat temperature readings for the roller operators on a colour screen (Trimble Heavy Industry, 2021). TCC is capable of monitoring pass numbers only or passes numbers in addition to temperature. The system automatically transfers registered data by the machine to the office using the Trimble SNM941 Connected Site Gateway (Trimble Heavy Industry, 2021). TCC can be seen in Figure 7 below.

Figure 7 Trimble Compaction Control (World Highways, 2017)

3.2.4 Challenges Associated with The Use of IC Technology

The IC measurement value (ICMV) can be used as an indicator for determining the stiffness or rigidity of pavement to a particular thickness (A. Mooney, 2010). However, previous studies have found just a few solid relationships between ICMV and on-site spot-testing outcomes of HMA (Commuri et al., 2011). Besides, different ICMV definitions provided by various roller vendors restrict the standardization and use of IC technologies on HMA compaction. On top of that, for numerous resurfaced projects, all rollers are set to vibrate off, and no ICMV output can be shown as an indicator for the roller operator (Hu, Shu, et al., 2017).

3.3 Technologies Adoption in Construction

The previous industrial revolutions have demonstrated that the adoption of digital technologies can reshape entire systems and increase the performance of industry sectors (Pereira & Romero, 2017). In the construction industry, Several nations have developed digitalization guidelines, such as the G20 Roadmap for Digitisation and Germany's Strategy for Work 4.0, to highlight the key aspects of digitisation (Brocca et al., 2018; Federal Ministry of Labour and Social Affairs, 2017).

Although the adoption of new technology in the construction sector is slower than in other sectors (Wang et al., 2020)., there are limited studies that looked into the difficulties practitioners have in implementing digital technologies and the potential strategies to encourage their adoption in the construction sector (Hwang et al., 2022). Digital innovations typically provide certain advantages and benefits for potential consumers, but frequently these advantages and benefits are not visible and clear to many of the intended users (Rogers, 2003).

Despite the complexity of HMA pavement activities in road construction, these activities rely significantly on workmanship (S. R. Miller et al., 2011). In fact, contractors choose working techniques based on tradition and rarely monitor critical process variables such as asphalt temperature, asphalt cooldown rates, asphalt compaction levels, and asphalt machine performance (Dorée et al., 2009).

Intelligent compaction technology is presented to monitor the important variables in asphalt pavement such as temperature and the stiffness of the road. Nevertheless, the road construction sector has not fully adopted this technology for multiple reasons. The first reason is that the incorporation of an IC system raises the price of the machine. According to the latest projections, the expense is around 30% greater than that of a normal vibratory roller (Horan et al., 2012).

Besides, the use of intelligent compaction technological advances raised the original construction costs by 2.5 %. The rise is attributed purely to the expenses of intelligent compaction software and the hardware applied to regular compaction machinery (Federal Highway Administration, 2015).

Furthermore, the uncertainty surrounding the results obtained through IC technology, particularly concerning the utilization of ICMV data instead of core data for density measurement (Yoon et al., 2018), has contributed to a lack of enthusiasm for the use of IC technology. Finally, contractors lack real motivation to fully adopt IC technology since there is no obvious financial model for their usage (Liu et al., 2020).

However, this research tries to focus on the perspective of roller operators to investigate the barriers that could cause this low usage rate among roller operators in companies already adopted IC technology. Diverse adoption and usability models are investigated in the next section. The goal was to find a model that focuses on the perspective of the end-user of the technology.

3.3.1 Technology Adoption Models

Multiple models and theories are used by researchers to examine the adoption of digital innovations in the construction industry.

3.3.1.1 Innovation Diffusion Theory

One of the adoption theories is the Innovation Diffusion Theory (IDT). In 1995, Rogers refined IDT after it was presented in 1962 (Moroni et al., 2015). IDT is concerned with determining how, why, and at what pace new ideas and technology diffuse in a community (Pottachola, 2021). According to Rogers, four key factors affect how quickly innovations are adopted: (1) invention features, (2) communication channels, (3) time, and (4) social system characteristics (Franceschinis et al., 2017). Many researchers in construction used the IDT to assess the adoption of new technologies in construction. For instance, to assess employees' perspectives regarding BIM adoption, Gledson (2016) examined BIM adoption decisions made by employees of an engineering organization using the innovation-decision process model from IDT. Kyriakou et al., (2020) utilized innovation attributes to evaluate the elements influencing Greek authorities' adoption of cloud-based computing. Moreover, by examining the effects of social systems in the execution processes, Lundberg et al., (2019)employed IDT principles to evaluate the spread of innovation in a Swedish contractor organization.

3.3.1.2 Social Cognitive Theory

Another model is Social Cognitive Theory (SCT), which took its cues from social psychology and was developed by considering three key variables: attitudes, personality, and environment, which operate in all directions to forecast both individual as well as group behaviour. Additionally, it can pinpoint strategies for altering and modifying behaviour (Rana & Dwivedi, 2015). The behaviour component in the SCT model is primarily concerned with usage, efficiency, and adoption difficulties. Personal factors are any features of an individual's personality, cognition, or demographics. Environmental influences also include social and physical elements that are external to the person physically, such as weather (Tahcerdoost, 2018).

3.3.1.3 Motivation Model

The Motivation Model (MM) is also one of the models used to assess the adoption rate. In this model, system utilization is primarily influenced by internal and external motivating factors (Taherdoost, 2018). External motivation is the idea that people are likely to be interested in a behaviour if they believe it will help them achieve desired results that are apart from the action itself, like greater job performance. The idea that people have the desire to engage in practice for no visible reward other than the fact of engaging in the activity itself is known as internal motivation. For instance, a felt benefit is an external drive while a feeling of pleasure is an inner drive (Taherdoost, 2018). In general, recognising the quality of output as well as perceived user-friendliness has an impact on felt benefits and feeling pleasure.

3.3.1.4 Technology Acceptance Model

The Technology Acceptance Model (TAM) is among the models used to investigate the adoption among the end users of specific technology. This model uses four behavioural factors. These are ease of use, attitude toward use, and behavioural intention to use which are measured using surveys to evaluate technology acceptance and usage (Davis et al., 1989; Davis, 1989). TAM2, an expansion of TAM, was created to incorporate social impacts and cognitive processes such as subjective norms, voluntariness, experience, and information quality (Venkatesh & Davis, 2000). In more recent times, TAM3 has been formed to take into consideration more elements that affect human decision-making, including computer playfulness, compute self-efficacy, computer anxiety and expectations of external control (Venkatesh & Bala, 2008). Nevertheless, TAM is seen as a good predictive model for use and acceptance.

3.3.1.5 Unified Theory of Acceptance and Use of Technology

The Unified Theory of Acceptance and Use of Technology (UTAUT), a development of TAM, has been designed to tackle the poor predictor of people's actual use of technology (Turner et al., 2010). UTAUT provides an opportunity to describe the actual intent to utilize a digital system by utilizing four categories: performance expectation, effort expectation, social influence, and facilitating conditions (Venkatesh et al., 2003).

3.3.2 Usability Models

The adoption of a certain technology is mostly a decision made by the management not by the individuals. Most adoption models focus on the decision-makers while examining the adoption of a certain technology within an organization. In usability models, the focus is directed to the end user to investigate the rate of adoption.

The term “Usability” refers to the extent to which a technology can be utilized by particular users to accomplish desired objectives with effectiveness, reliability, and satisfaction (Lacerda & von Wangenheim, 2018). There are several models developed since 1980 to assess the usability of technologies by the end user (Sauro, 2013). Focusing on support systems, there are numerous standards and models to evaluate the usability of these systems in the aerospace and automotive sectors (Beringer & Ball, 2002; Brown et al., 2020; Landau, 2002).

3.3.2.1 ISO Usability Model

Three usability attributes were identified by the ISO98: efficiency (how well resources were used for the sake of effectiveness); satisfaction (relief and positive user interaction while operating the software); and effectiveness (demonstrating the level of accuracy and completeness of goal achievement) (Alturki & Gay, 2017). The usability elements that need consideration were expounded upon in the ISO98 (Alturki & Gay, 2017). These were the user (the individual interacting), the purpose (or primary objective), and the context of use (people, tasks, the tool being used, and the surrounding environment). Every one of these elements influences the overall design of the software. It has an impact on how users engage with the system, specifically (Keates, 2004).

3.3.2.2 Nielsen Usability Model

Nielsen was one of the first people who recognized the characteristics of usability. The approach of Nielsen had four characteristics. These are Effectiveness, Efficiency, Satisfaction, and Learnability (Nielsen Jakob, 1994). Thereafter, Nielsen added Memorability and Errors to his new model and eliminated Effectiveness. He indicated the following characteristics (Nielsen, 2012):

- Efficiency: The resources used to accurately complete a task in order to meet user objectives.
- Learnability: the system's capacity to be quickly and easily learned so that users may begin using it to complete tasks in the shortest period of time.
- Satisfaction: The product should make the customer feel comfortable and have an optimistic perspective on using it.
- Errors: The system should have a low error rate to minimize the number of mistakes the user makes when utilizing it. If mistakes are made, they should be simple to fix. Last but not least, disastrous mistakes must be avoided.
- Memorability: The system should be easily remembered, so that even a casual user may start utilizing it after a significant amount of time.

3.3.2.3 National Aeronautics and Space Administration's Task Load Index

The National Aeronautics and Space Administration Task Load Index (NASA-TLX) is the most extensively used and verified method for calculating total workload following task completion (Said et al., 2020). NASA-TLX model employs a mean value of evaluations for six categories, including mental demand, physical demand, temporal demand, own performance, effort, and level of dissatisfaction. This model is used frequently to collect and evaluate subjective workload values (Hart, 2006). NASA TLX is shown to provide a more complete evaluation method in comparison with other models (Rubio et al., 2004).

3.3.2.4 System Usability Scale

The System Usability Scale (SUS) is a commonly utilized standardized questionnaire designed to evaluate overall usability (Lewis, 2018). When using a SUS, participants are asked to rank each of the ten items below using a scale of one to five, representing strong agreement to strong disagreement (Usability.gov, 2023):

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.
4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

3.3.3 The Developed Method

This research aims to involve the majority of factors that could influence the use of OSS by roller operators. This includes the technical and non-technical (social) aspects that could affect the use of IC systems by roller operators. Therefore, combining a usability model with another model that considers the social aspects could complete the frame of the research.

Makarov et al., (2021) have investigated the most relevant criteria that can be used in construction and specially to assess the usability of OSS. They used SUS next to NASA TLX to produce reliable measures for the usability of OSS. The authors have modified these two models to a slight extent by adding several criteria to coincide with the unique OSS compaction characteristics (Makarov et al., 2021). The research method used by the authors can be seen in Table A in appendix A.

Numerous models have been explored to determine the most suitable model needed to complete the frame of this research. Research that has been done on health information exchange technology (Watkinson et al., 2021) used the UTAUT model in combination with 2 useful TAM criteria to assess the use and acceptance of this technology by end users has been found. This model focuses more on the social aspects of the adoption of new technology. The research method developed by Watkinson et al., (2021) can be seen in Table B in appendix A.

It has been found that the research method developed by Makarov et al., (2021) in combination with the research method developed by Watkinson et al., (2021) can be used to cover the technical and non-technical aspects associated with the use of IC systems. To illustrate, Makarov et al., (2021) focused in their research method on the technical aspects related to the use of technology. On the other hand, Watkinson et al., (2021) focused in their research method on the social aspects related to the use of a specific technology. Therefore, the combination of these two research methods allows for covering the technical and social aspects related to the use of IC systems by roller operators.

The criteria used by Makarov et al., (2021) And Watkinson et al., (2021) methods are combined to produce a new method as can be seen in Table 2 below.

Table 2 The research method

Criteria	Survey question	Measurement
Interaction	The provided support encourages you to interact with it frequently	Score 1 to 5 where: 1- Completely disagree. 2- Disagree. 3- Neutral. 4- Agree. 5- Completely agree.
Clearness	The provided support provides clear information	
Comprehension	The provided support uses understandable visuals	
Ease of use	The provided support provides information that is easy to follow	
Non-overloading	The provided support does not overload you with information	
Non- distraction	The provided support provides you with information in a non-distracting manner	
Visualization	You would rather have the information in 3D	
Helpfulness	The provided support helps in the decision making	
Assistance	The provided support helps to find points of attention in the operation	

Instructiveness	The provided support helps improve your skills	
Explicative	The provided support helps see how other operators are working	
Collaboration	The provided support helps collaborate with other operators results	
Effectiveness	The provided support helps achieve higher-quality asphalt	
Performance Expectancy 1	The provided support can save me time at work	
Performance Expectancy 2	The provided support makes my job easier	
Effort Expectancy 1	Learning how to use OSS was easy for me	
Effort Expectancy 2	It is easy for me to become skilful at using OSS	
Perceived Enjoyment	OSS is enjoyable to use	
Social Influence 1	People in my workplace promote the use of OSS	
Social Influence 2	Most individuals in my workplace use OSS	
Facilitating Conditions 1	I received adequate training before I begin using OSS	
Facilitating Conditions 2	I can receive help when I have difficulties using OSS	
Use recommendation	You recommend the use of the system	

However, the two lists from Makarov et al., (2021) And Watkinson et al., (2021) literature have multiple evaluative criteria. The researcher has set three standards to eliminate criteria from Makarov et al., (2021) And Watkinson et al., (2021) lists. These standards are explained in Table 3 below. Each criterion in the two lists that meet the standards in Table 3 is excluded.

Table 3 Standards for excluding criteria

Standard	**Explanation of standard**	**Reason for using this standard**
Redundancy	Criteria in the two lists from two different sources and there is an overlap.	Asking the same question will not increase the productivity of the developed list.
Irrelevant to the research question	Criteria are rephrased in the context of this research thesis and are still irrelevant to the research question.	Answers to associated survey questions of criteria will not help answer the research question.
User experience compatibility	Associated survey questions of the criteria are general/broad, excessive and confusing.	Keeping the list practical, minimizing the chance of not filling out the survey by roller operators.

Table 4 below represents the removed criteria from Makarov et al., (2021) And Watkinson et al., (2021) lists.

Table 4 Removed criteria

Criteria to exclude	Associated Survey question	Reason of removal
Actionable (Makarov et al., 2021).	Looking at the provided information, you know what you need to do.	Redundant criterion that is already used in the developed list. The corresponding criteria is "Clear" (Makarov et al., 2021) and the associated survey question is "The provided support provides clear information".
Informative (Makarov et al., 2021).	The provided support helps improve your knowledge about asphalt operation.	User experience compatibility. The term knowledge is too broad.
Supportive (Makarov et al., 2021).	The provided support helps make faster decisions about your strategy.	Redundant criterion that is already used in the developed list. The corresponding criteria is "Helpful" (Makarov et al., 2021) and the associated survey question is "The provided support helps in the decision making".
Performance Expectancy (Watkinson et al., 2021).	• Using HIE helps me to be a better healthcare provider. • Using HIE supports critical aspects of my patients' healthcare. • Using HIE enhances my effectiveness as a healthcare provider. • HIE is useful to me in managing my patients' healthcare.	The first criterion is redundant criteria that is already used in the developed list. The corresponding criteria is "Instructive" (Makarov et al., 2021) and the associated survey question is "The provided support helps improve your skill". The second criterion is irrelevant to the research question. Answering the question will give no insight. The third and fourth criteria are redundant criteria that are already used in the developed list. The corresponding criteria is "Instructive" (Makarov et al., 2021) and the associated survey question is "The provided support helps improve your skill".
Effort Expectancy (Watkinson et al., 2021).	I find HIE easy to use.	Redundant criterion that is already used in the developed list. The corresponding criteria is "Effort Expectancy" (Watkinson et al., 2021) and the associated survey question is "It was easy for me to become skilful at using HIE".

Job Relevance (Watkinson et al., 2021).	• In my job, using HIE is important. • The use of HIE is pertinent to many of my job-related tasks.	User experience compatibility. The listed associated questions of the criteria are broad, obvious and give no insight.
Habit (Watkinson et al., 2021).	• The use of HIE has become a habit for me.	The listed associated questions of the criteria are irrelevant to the research question. The question is a yes/no question that will not lead to further discussion in the interviews and will not contribute to answering the research question.
Behavioural Intention (Watkinson et al., 2021).	• I intend to use HIE regularly. • I intend to increase the amount I use HIE in the future.	The listed associated questions of the criteria are irrelevant to the research question. Questions are in future tense which this research is not concerned with.
Social Influence (Watkinson et al., 2021).	People who influence my behaviour at work use HIE.	Redundant criterion that is already used in the developed list. The corresponding criteria is “Social Influence” (Watkinson et al., 2021) and the associated survey question is “Most individuals in my workplace use HIE”.
Facilitating Conditions (Watkinson et al., 2021).	I have the knowledge necessary to use HIE.	Redundant criterion that is already used in the developed list. The corresponding criteria is “Facilitating Conditions” (Watkinson et al., 2021) and the associated survey question is “I received adequate training when I began using HIE”.
Facilitating Conditions (Watkinson et al., 2021).	• I have the resources necessary to use HIE. • HIE is compatible with the other electronic health systems I use at work. • Viewing my patient's prescribed medications. • Viewing my patient's timeline of encounters.	User experience compatibility. In the first criterion the term resources is too broad. The rest of criteria are too specific, and not adaptable to this study work.

4. Results

In this chapter, the collected data from surveys and interviews are analysed in detail. Thereafter, the results are validated. Finally, the outcome of surveys and interviews is summarized.

4.1 Surveys Results

The survey data was analysed using descriptive analysis. The results can be seen in Table 6 below. These results are based on the input of a total of 43 roller operators. As can be seen in Figure 8, the roller operators that have filled in the survey list are 20 out of 24 roller operators from BAM, 22 out of 29 roller operators from KWS, and one roller operator from Heijmans. The number of roller operators who have not filled out the survey from Heijmans is not shown in the figure since the total number of roller operators in Heijmans is unknown to the researcher.

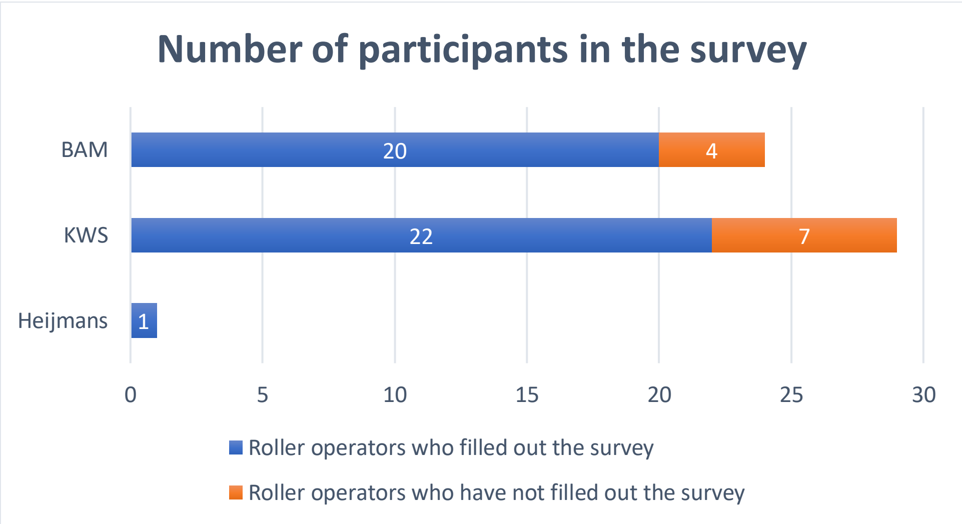

Figure 8 Number of participants

Figure 9 shows the percentage of roller operators who participated in the research survey based on their years of experience. Most of the participating roller operators have more than 20 years of experience in asphalt compaction.

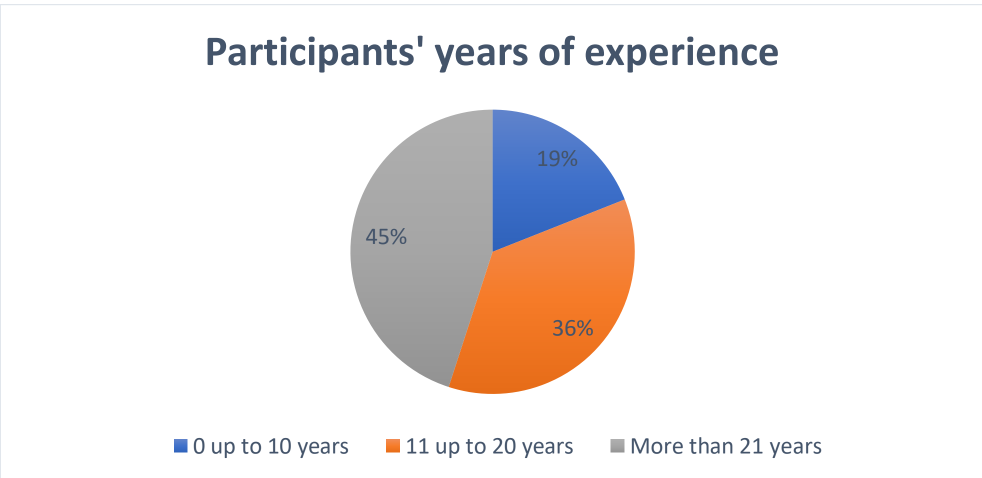

Figure 9 Participants' years of experience

The survey results are interpreted based on the values proposed by Alston et al., (2002). These values can be seen in Table 5 below. It has been assumed that the mean values below 2.5 represent the dissatisfaction of roller operators against a specific point in the survey while the roller operators' satisfaction with a particular survey point is indicated by mean values equal to or greater than 3.5.

Table 5 Scale range (Alston et al., 2002).

Scale	Range	Interpretation
Strongly Disagree	1.00-1.49	Strongly unsatisfied
Disagree	1.50-2.49	Unsatisfied
Neutral	2.50-3.49	Neutral
Agree	3.50-4.49	Satisfied
Strongly Agree	4.50-5.00	Strongly satisfied

Furthermore, the results are ranked based on the mean value to present the biggest and smallest barriers against the use of IC technology. It can be seen in Table 6 below that the biggest barrier is social influences, and the smallest barrier is the clearness. A detailed explanation of these barriers will follow in the sub-sections below. Moreover, P- value is calculated to indicate the significance of the survey data of BAM and KWS. Results show no significance difference between the data in most aspects.

Table 6 Survey results

Criteria source	Criteria	Mean OSS	Standard deviation	Rank	P-value
Makarov et al., (2021)	Interaction	2,16	0,90	5	0,215
	Clearness	3,79	0,74	22	0,063
	Comprehension	3,63	0,69	21	0,508
	Ease of use	3,14	0,74	14	0,056
	Non-overloading	3,79	0,74	22	0,411
	Non- distraction	2,02	0,94	3	0,219
	Visualization	3,02	0,60	13	0,297
	Helpfulness	2,26	0,82	9	0,712
	Assistance	2,37	0,76	12	0,547
	Instructiveness	3,14	1,01	14	0,330
	Explicative	2,33	0,84	11	0,849
	Collaboration	2,14	0,86	4	0,087
	Effectiveness	2,16	0,90	5	0,028
Watkinson et al., (2021)	Performance Expectancy 1	2,16	0,53	5	0,042
	Performance Expectancy 2	2,30	0,96	10	0,531
	Effort Expectancy 1	3,33	0,64	19	0,233
	Effort Expectancy 2	3,28	0,67	17	0,819

	Perceived Enjoyment	3,21	0,67	16	0,814
	Social Influence 1	1,86	0,97	2	0,107
	Social Influence 2	1,79	0,91	1	0,003
	Facilitating Conditions 1	2,16	0,57	5	0,138
	Facilitating Conditions 2	3,56	0,80	20	0,568
Makarov et al., (2021)	Use recommendation	3,28	0,77	17	0,089

A representation of the survey results is made in Figure 10 below. The figure shows the satisfaction degree of roller operators regarding survey criteria points. It can be seen that Clearness, Comprehension and Non-overloading scored the highest in terms of satisfaction while social influences and distraction were the lowest in terms of satisfaction.

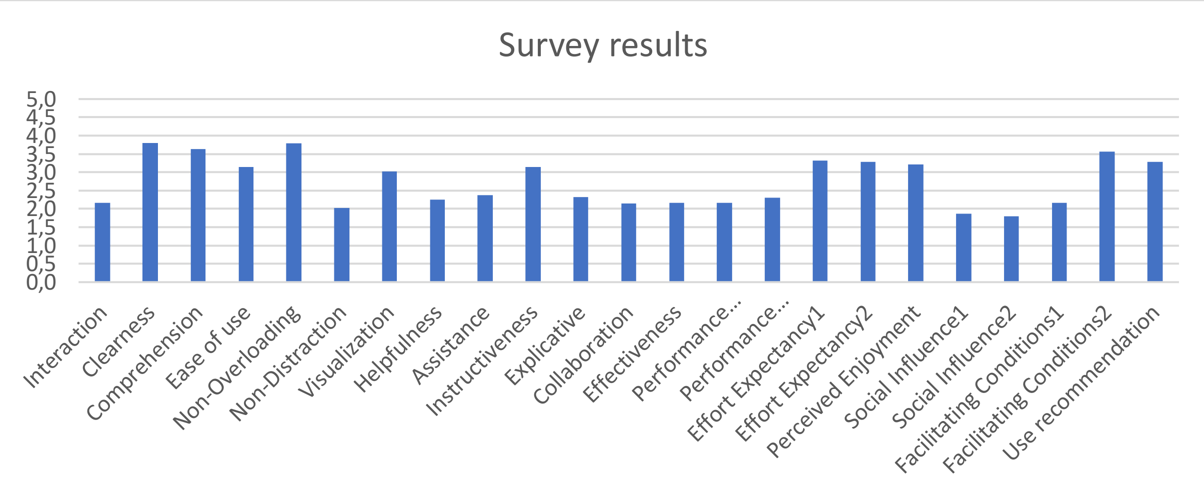

Figure 10 Survey results

Figure 11 represents the satisfaction ranking of roller operators, ranging from high satisfaction to low satisfaction for each survey point. The colours in the figure represent the satisfaction degree as indicated in Table 5. However, it is evident that roller operators are less satisfied with social aspects compared to technical aspects.

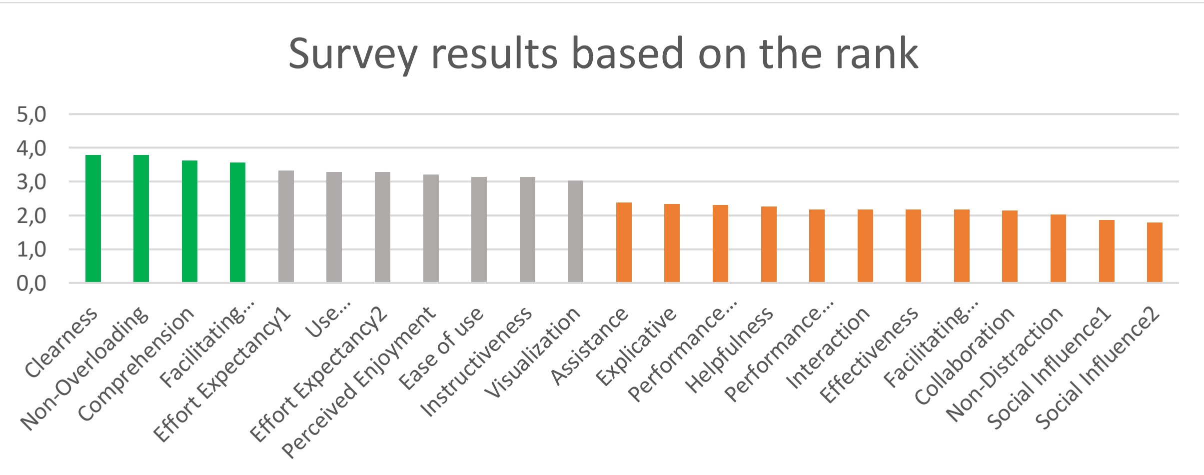

Figure 11 Survey results based on the rank

In Figure 12 below, a comparison has been made between the roller operators who have up to 10 years of experience with other roller operators who have more than 10 years of experience. It can be seen that the young generation of roller operators is more satisfied with the use of IC systems.

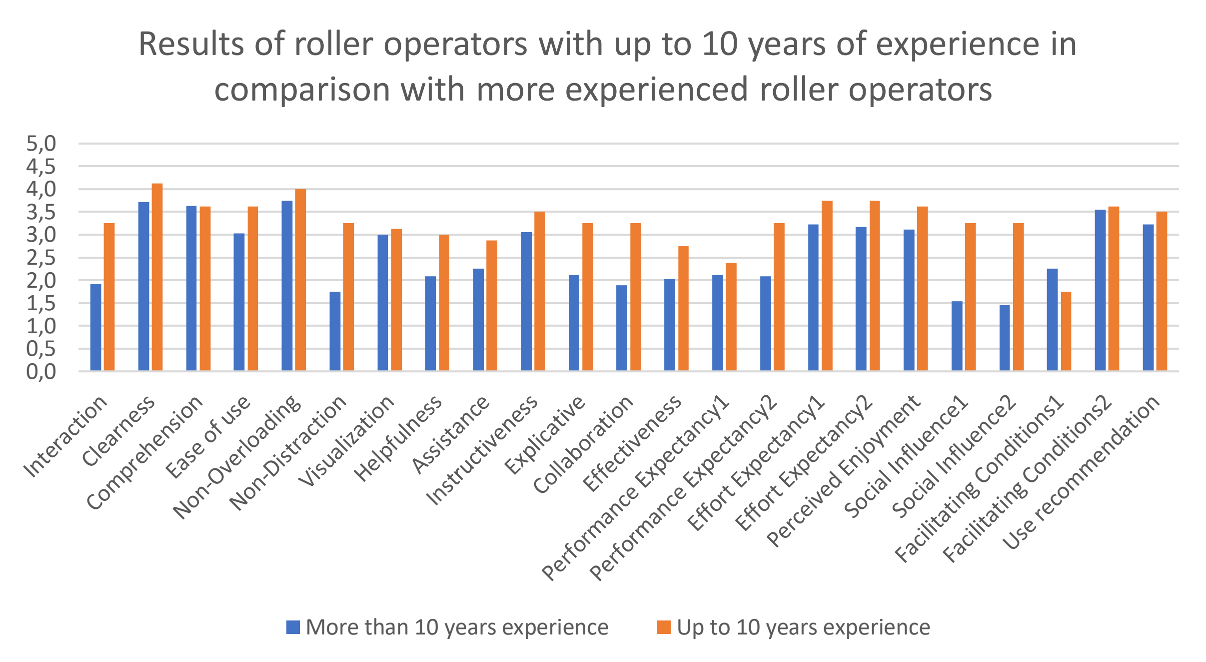

Figure 12 Young roller operators compared to others

4.2 Interviews Results

Interview results are analysed using thematic analysis. Since the interviews were meant to investigate the reasons behind the satisfaction and dissatisfaction of roller operators regarding the survey points, a connection has been made between each survey criterion and related interview outcome as can be seen in the subsections below. This allows a deeper understanding of the reasons behind the obstacles related to the use of IC systems.

4.2.1 Interaction

Based on the survey results, the IC systems seem to be non-encourageable for interaction for roller operators. IC systems received a 2.16 on this factor, which is considered unsatisfactory by roller operators. The survey results have shown that these systems lack the ability to be attractive to roller operators. This is related to the following subjects:

4.2.1.1 Accessibility of the Language and User Attraction

The first factor is the system language where some systems such as SD are available in English and German while not available in Dutch. This could make the use of SD or any version of OSSs that does not support Dutch unattractive for roller operators especially because not all roller operators can read English and depend heavily on their mother language. One of the roller operators mentioned the following:

"It's strange that the system does not have a Dutch language option, if the manufacturer develops a system, it should be also available in Dutch."

Validation experts acknowledged the need for a system that supports the language of users since not all roller operators are able to understand English or any other foreign language.

4.2.1.2 Setup Challenges in IC Systems

The second factor is the instillation of the system before starting work. This varies from system to system. For instance, roller operators find the setup of HCQ and TCC to be natural, while they find the instillation of SD unsmooth and require time. The following was stated by one of the roller operators:

"Setting up a project in the Smart Doc system seems to be straightforward but requires a lot of work and cost time. This makes me feel bored."

Roller operators underline that scanning a barcode to obtain the necessary data to start a project would be simpler than manually entering the data. They think that such a concept would make the launch of a project in IC systems simpler and more effective.

Experts discussed the difference in the ease of setup level of different IC systems. They expressed that the setup of some systems is straight forward while others are not. Experts, however, emphasized the need to make the setup of IC systems easy for roller operators in order to encourage them to use these systems.

4.2.1.3 Simplicity and Complexity of User Interfaces in IC Systems

The third factor is the lack of knowledge about what the buttons and options on the screen of systems further offer. Roller operators do not understand all the buttons and options on the screen. One of the roller operators stated the following on HCQ:

"I know how to create a project, but the whole top buttons on the screen, I have no idea what I can do with them."

Validation experts agree that there are a lot of buttons on the system's screen, but roller operators do not have to use them. Therefore, the user interface is made simpler with fewer buttons in the new system (Smart Doc.).

4.2.2 Clearness

The information displayed by the support systems is shown to be clear for roller operators. IC systems scored 3.79 on this point which can be indicated as satisfactory for roller operators. However, the following subject is raised during interviews:

4.2.2.1 Information Representation in IC Systems

the majority of roller operators indicated that having the temperature of the asphalt mat as a number is more efficient than having it as a plot. HCQ and SD present the temperature of the asphalt mat as a plot while TCC presents it as a number on the screen.

Validation experts recognized this issue and noticed that roller operators often watch and navigate at the temperature on the dashboard, not on the IC screen. Nevertheless, validation experts emphasized the significance of temperature maps for road authorities.

4.2.3 Comprehension

The interpretation of the plots displayed on the screen of OSSs seems to be an easy task for roller operators. On this aspect, IC systems received a score of 3.63, which is considered satisfactory by roller operators. Nevertheless, the following subject is raised during interviews:

4.2.3.1 Plot Interpretation Simplicity in IC Systems

the majority of roller operators have stated during interviews that using a tablet instead of a relatively big, fixed screen where the roller operator can control the place of support in his roller cabin is a wise choice. Using a tablet is easier, that is what most roller operators agree on.

Validation experts showed understanding of the easiness of having the tablet to check the temperature plots and further control the process by roller operators but because of safety concerns, the new system with a tablet option (Smart Doc.) will be located in the same fixed place as the old systems.

4.2.4 Ease of use

The information that the support systems provide is easy to follow to a normal extent. IC systems received a 3.14 on this factor, which is considered neutral by roller operators. However, the following subject is raised during interviews:

4.2.4.1 Information Accessibility in IC systems

Most roller operators who have been interviewed indicated that displaying the temperature as a number or replacing the normal screen with a tablet could make the information easier to follow since the operators in this case will focus more on the number of passes they perform and do not have to focus on both temperature and roller passes number. Besides, having a tablet instead of a fixed screen enables the roller operator to place the tablet in a near place to hem where he can see the information better.

Same as 5.3, validation experts discussed the importance of safety and visibility for operators. This theme emphasizes the priority placed on safety and unobstructed visibility.

4.2.5 Overloading

The system is seen as nonoverloaded by roller operators. IC systems scored 3.79 on this point which can be indicated as satisfactory for roller operators. Validation experts relate that to the case where a large number of roller operators might consider IC systems as registration systems rather than support systems. Therefore, they depend more on their experience in doing their work.

4.2.6 Distraction

Most of the roller operators feel distracted while using the OSSs. IC systems scored 2.02 on this point during the survey which can be indicated as dissatisfactory for roller operators. Interview results show that the distraction is caused by multiple reasons as explained below. This is related to the following subjects:

4.2.6.1 Impact of GPS Signal Interruptions on the Performance of the Roller Operator

One of the reasons that makes roller operators feel distracted is the GPS signal interruptions. The GPS signal can be interrupted in most systems and result in missed spots in the registration which makes roller operators confused and distracted.

“Signal reception is interrupted continuously. In a free field, there is no problem at all but if there are trees, tunnels or high buildings then you see that reflected in your image. So you do miss some spots in the registration and you get distracted”.

Furthermore, sometimes IC systems stop working suddenly and do not respond anymore which makes roller operators distracted as well.

“System has crashed. OK, then I'll start it again. If he crashed again during my work? Well. I consider that the system broke down and I won't use it.”

Validation experts confirmed the issue of losing the GPS signal since it can be seen back in the data registered by IC systems which may lead to potential distractions for operators. They also indicated that some systems stop working suddenly.

4.2.6.2 Safety Issues and Distractions in the Use of IC Systems

Scanning the plots and interoperating the information obtained from the IC system require concentration from roller operators. Roller operators have to focus on multiple factors at the same time. For instance, the roller operator has to keep an eye on the gauges he has in his cabin, monitor the movement tempo of the asphalt spreader, and focus on the movement of other rollers and the workers on site. Therefore, roller operators argue that sometimes they ignore the IC system because of safety concerns especially when they work near an open bike path. An interviewee expressed concerns about the safety issues caused by the distraction when he mentioned the following:

” Well, I look at my work, but you look at the support system then, you going to do this automatically and if you then for example work on provincial roads with road users as cyclists at the side of the road. There is something that can happen, so the safety, that's what matters to me.”

In order to prevent being distracted while working, roller operators mentioned that they frequently turn the screen up. They only infrequently use IC systems to see if they missed any locations while compacting the asphalt.

“I do still use it when I have rolled a long distance. Then I zoom out and check if it's a nice even colour. Because then I also know, okay, I've been everywhere. But that's more for myself."

Validation experts showed an understanding of such a point. They expressed that the compaction process requires a lot of attention from roller operators. The experts underlined that the operator's main attention should be on securely operating the machine and compacting asphalt with brief looks at the IC screens in between.

4.2.6.3 Distractions and Screen Integration in IC Systems

The many screens in the latest generation of rollers are a problem according to roller operators. The presence of too many screens could cause less visibility for roller operators.

“Next to the Smart Doc. screen in the new tandem roller, there is already a screen where it can sense where it should vibrate. Then you have all kinds of camera screens. I think they also want to hang another screen for the roller spreader. All these screens being in the roller is too much at a given moment, because. Then your whole cabin is actually full of screens”

A combination of multiple screens in the cabin of roller operators with IC systems is seen by roller operators as a possible solution for less distraction. For instance, the new rollers equipped with an SD system has also Smart Compaction system. This system provides automatic support functions for roller operators such as vibrating. The possible combination of this system with SD could lead to less distraction for roller operators since they have to consider one screen instead of two.

Validation experts confirmed that having too many screens can be distracting since not all roller operators are able to multi-tasking during work. Therefore, an integrated display is desired. The experts emphasize the importance of simplicity in minimizing distractions.

4.2.6.4 Improving Screen Positioning for Better Operator Vision in IC Systems

Another reason for distraction is the fixed position of the OSS screen of some systems such as HCQ and TCC. The current position could be not ideal since it is located on the left corner of the cabin which could be far from the insight of roller operators especially for old roller operators. Roller operators think that IC systems should be located in a space where the view is not obstructed.

A possible solution suggested by roller operators for this issue is integrating the screen with the dashboard of the roller as mentioned by a roller operator.

"I would put the display on the controller (dashboard) itself. That is of course the best."

Validation experts agreed that the big screen of the old version could hinder the full visibility of roller operators. They mentioned that the new systems in the market tend to use smaller screens to maintain full visibility for roller operators.

4.2.6.5 Night-time Work Distractions in IC Systems

Even though roller operators consider IC systems helpful at night work, they mentioned that they get distracted by screen lights at night work. Although the brightness could be adjusted manually in systems such as SD and TCC, roller operators still consider the screen light distracting in night work. Adding a night shift mode that can be turned on to make screens emit less light might be a good solution for this issue (Breus, 2022).

Validation experts acknowledge that some systems cannot dim properly which can be uncomfortable at night. They mentioned that there are ideas to solve this issue, but not implemented yet.

4.2.6.6 Obstacles in IC Systems for Offset Movement and GPS Registration

The last reason that makes roller operators feel distracted is the registration of offset movement issues. IC systems register the offset rolling where roller operators overlap the front and rear roller passes as a normal movement. To illustrate, if the roller wheel's width is two meters and the total width during the offset movement is 2.5 meters, then the system registers only two meters as default. Thus, the system registers what happens in the middle and not the sides. That happens because the GPS sensor is located in the middle of the roller and takes only the standard width of the roller during registration.

"That is not good for me, because I compacted the sides just like the middle. The system does register, but it registers only the middle."

Validation experts confirmed that some systems do not consider the offset rolling during registration and see it as a logic reason for causing confusion for roller operators. However, experts declared that the HCQ system does register the offset rolling. The reason that roller operators who use HCQ are not aware of this ability could be related to the lack of training as explained in 5.17.

4.2.7 Visualization

Survey results have shown that roller operators have no specific preference for 2D or 3D visualization. On this aspect, IC systems received a score of 3.02, which is considered neutral for roller operators. Interview results have shown that the only system that provides support in 3D is SD. Only a specified number of roller operators had the chance to work with this system at the time of this research. Therefore, having good insight into what this feature can offer is unclear. However, during the interviews some roller operators mentioned having the street view in SD seems useful but at the same time, it can be confusing because the lines of registered plots are smaller.

Validation experts clarified that this may be the case given that the system displays an out-zoomed figure during ordinary setup. However, zooming is always an option. This confirms the need for training for roller operators as mentioned in point 5.17 in order for them to be able to use the new system efficiently.

4.2.8 Helpfulness

Roller operators consider IC systems not to help in decision-making during compaction. IC systems scored 2.26 on this point which can be indicated as dissatisfactory for roller operators. There are multiple reasons behind this idea raised in the interview results as explained in the following paragraphs:

4.2.8.1 The Importance of Observation and Experience in Compaction Decision-Making

Roller operators cannot rely only on the OSS because they think that the technology is not mature enough to help them in decision-making during compaction. While operating heavy machinery on uneven ground, roller operators rely on their experience to identify areas of concern. Indicators provided by IC systems are considered insufficient for decision-making during compaction by roller operators. Areas of concern are indicated by changes in the colour and texture of the ground which cannot be recognized by IC systems and roller operators must rely on their own observation and experience to identify them.

Roller operators also pay attention to the asphalt's quality and any soft patches in the vicinity. Roller operators think that a machine cannot offer this kind of knowledge. Overall, roller operators think that when it comes to spotting possible threats, IC systems cannot replace the benefits of experience and observation.

Validation experts acknowledged the skill of roller operators and their capability to evaluate circumstances on-site exceeding what the technology offers. Furthermore, roller operators describe how they make use of their observations to inform colleagues about the state of the terrain they are operating on. To make sure that everyone is aware of these locations, they use the information they collect to inform others. IC systems are not capable of detecting this. Through effective communication, accidents can be avoided, and work can be completed without delay. Experts in validation sessions stated that IC systems could fail to allow for enough data sharing and communication.

4.2.8.2 IC System Limitations in Detecting Under- and Over-compaction

Despite the assistance offered by IC systems, these technologies are unable to identify under- or over-compacted areas. Roller operators cannot rely only on temperature to determine the best roller passes needed to reach the appropriate asphalt density and avoid under or over-compaction. The patterns roller operators must adhere to get optimal compaction depending on a number of circumstances. Therefore, roller operators want to have a function that helps them to detect the suitable amount of compaction. Validation experts confirmed that detecting the degree of compaction using IC systems is the wish of most roller operators. However, they stated that the technology is not developed yet to offer such a function.

Moreover, IC systems are unable to identify compositional alterations in asphalt that are being compacted, such as changes in the type or size of the particles. The densities of various aggregate types can vary, and IC systems are unable to distinguish between them. In these circumstances, the operator might need to rely on their knowledge and estimation to modify the compaction process to consider the uneven conditions. Validation experts confirm that IC technology might not be able to provide such functions and that the skills and capabilities of roller operators are important to evaluate the conditions on-site.

4.2.8.3 Concerns with Temperature Measurements in IC systems

The temperature readings of the old version of rollers might be not reliable, according to roller operators. This could be related to multiple issues. First, the temperature sensors in the old version of rollers are located at the front and back. The temperature displayed then for the roller operator in this case represents the average temperature of the front and rear temperature sensors and not the actual temperature of the asphalt mat. Besides, the spreader attached to the roller might influence the temperature the back sensor acquires, leading to unreliable temperature readings. On top of that, roller operators noted that when using a specific kind of roller with a big container attached to it, the temperature measuring sensor on this sort of roller is frequently obscured by the container, resulting in less accurate temperature readings. However, the temperature sensor is positioned in the centre beneath the roller in the newer models of the roller, resolving this issue.

Second, roller operators note that the temperature readings in the HCQ system might not be accurate. The reason behind that is the colour code provided on the screen of HCQ instead of a precise numerical measurement. The difference between colour codes on the screen is 10 degrees which makes it difficult for roller operators to identify the precise temperature of the asphalt mat.

Validation experts confirmed the mentioned problem in HCQ since the attached parts to the rollers could hinder or effect the temperature reading. However, this problem is identified and solved in the new versions of rollers. These versions will be the most in-use rollers in the coming period. Furthermore, validation experts mentioned that this is not the case with the TCC system. TCC is used in rollers where the temperature sensor is located in the middle of the roller and TCC provides also the temperature in numbers on the screen. However, validation experts added that there is a doubt about the accuracy of temperature sensors used in IC systems since the measurements of these sensors can be affected by wind and other circumstances. Therefore, the temperature measurements are not always accurate.

4.2.8.4 Limitation of IC systems in Incorporating Compaction Conditions

The roller makes it clear that the IC system might be able to register the data, but it lacks the ability to assist the user in making optimal decisions at the moment. To illustrate, the support function in some IC systems that enables roller operators to fill the desired number of passes is viewed as useless by roller operators. This is because determining the required number of passes necessitates consideration of multiple factors, such as weather conditions or the state of the road's foundation, which IC systems do not measure. For instance, TCC gives based on the type of mix roller operator installed, the number of passes you need to reach the required compaction. These passes are decided by the people in the laboratory, based on their experiments. The problem is that is not always correct (correct only in optimal conditions) because other factors could influence the number of required passes such as the weather conditions, and the effect of under layer(foundation) if it was wet for example. These factors are not taken into account when the number of passes is determined.

"Nice to get four roller passes is enough on your screen, but if the asphalt cools down faster because of weather conditions, then you're maybe not done with 7 roller passes."

Therefore, roller operators cannot always follow what the system provides. Further development in IC systems that makes these systems able to predict the number of optimal roller's passes based on multiple factors that can be filled in the systems could be a big addition and promotion for IC systems.

Validation experts mentioned that such advancement in technology requires further development in IC technology. An alternative could be a possible filling of compaction conditions manually by roller operators in the IC system could help the management to interoperate the reason behind a specific behaviour of roller operators and enhance the communication between the management and roller operators.

4.2.8.5 The Demand for Vibration Recording in IC Systems for Enhanced Decision-Making

IC systems do not register the places where roller operators have used the vibration. Based on roller operators' insights, such a function could help roller operators remember where they have been vibrated and thus make better decisions, especially in big-scale projects. Validation experts mentioned that HCQ can register the vibration process while SD and TCC are not.

The necessity of human judgment in decision-making is emphasized by roller operators, especially in circumstances when machinery and technology could have restrictions. They also emphasize the necessity of continuing advancements in machine systems technology and the significance of trustworthy and accurate data for making sensible decisions.

4.2.9 Assistance

IC systems received a score of 2.37 on this aspect, which is considered unsatisfactory for roller operators. During interviews, roller operators emphasise the importance of the support IC systems provide but at the same time, they miss more valuable support that could help them in finding points of attention in the compaction operation. This is related to the following subject:

4.2.9.1 Optimization of Temperature Monitoring in IC Systems

Roller operators mentioned that IC systems provide them with the temperature readings which are already available on their dashboard. Besides, roller operators must travel to a specific point on the asphalt mat to take the temperature reading. They consider this operation unpractical.

Roller operators emphasize the significance of temperature management at this stage. The person operating the roller must keep an eye on the temperature and choose how frequently to roll over the asphalt. Roller operators claim that it would be simpler to predict when the asphalt is suitable for rolling if the temperature readings for a distance ahead could be shown on the roller's display. To prepare for rolling over the asphalt in advance, it would be also beneficial to have a wider temperature reading before the asphalt spreading machine. The operation would run more smoothly and effectively, according to roller operators, if there were more temperature readings.

"Those systems measure the temperature below your roller, so not further around you. I would think it a good one if we could see the temperature directly behind the asphalt spreader. The spreader machine also has such a system, of course, and it measures the temperature immediately behind the beam, and if you could link that with each other, you would know, for example, oh, it is now getting a bit cold behind the machine, so then I have to be there sooner."

Validation experts confirmed this issue and recognized the usefulness of having such knowledge to prevent mistakes and make necessary modifications while working. Therefore, validation experts that there is ongoing work on this issue and that such development might come soon.

4.2.10 Instructiveness

IC systems received a 3.14 on this factor, which is considered neutral for roller operators. Interview results have shown that roller operators depend heavily on their experience in executing their job tasks. They consider IC systems to be neutral in terms of improving their skills in compacting. This is related to the following subject:

4.2.10.1 The Use of Recorded Data in IC Systems

Considering IC systems to be neutral in this term is more related to the manner in which the management deals with the data gained from IC systems. To illustrate, Data registered every workday by IC systems is kept by the management and either analysed occasionally or not analysed at all. The reason behind that is the difficulty of analysing the data registered by IC systems. This results in a lack or absence of feedback given to roller operators on results. Roller operators mention that they rarely hear feedback about their use of IC systems, except when something goes wrong. This makes improving roller operators' skills by using IC systems unfeasible.

Roller operators stress the value of getting feedback on their performance and propose that regular project reviews would be useful in this sense. In addition, they indicate they are open to feedback. Additionally, they call for putting more emphasis on the viewpoints of technology users, in this case, operators of machinery.

" I think if you receive feedback once in a while about it, for example by sending an overview of such a project, it will be useful because then you have the feeling that you actually do it for something and not just that you have to."

Roller operators also emphasize the significance of having a thorough awareness of the entire work progress at the close of the working day. That could help them to comprehend their work better and spot opportunities for improvement.

Validation experts mentioned that the registered data is usually communicated with the asphalt team leader but fewer times in the last period. Therefore, it is understandable why roller operators mention this point.

Overall, validation experts highlighted the significance of sharing data gathered by systems with machine operators. They emphasized how important it is for operators to understand their performance and take lessons from it to develop their abilities. The inability to effectively communicate with machine operators was identified as a potential problem.

4.2.11 Explicative and Collaboration

IC systems scored 2.33 average on Explicative and 2.14 on Collaboration which can be indicated as dissatisfactory in both cases for roller operators. This is related to the following subject:

4.2.11.1 Challenges and Restrictions of Connection between Rollers in IC Systems

Interview results have shown that systems such as HCQ and TCC provide the feature of connecting rollers. However, this feature has multiple drawbacks that make roller operators either not know how to use it or even not use it at all. Connecting rollers might be challenging for roller operators. For them, the process is difficult. In HCQ, for instance, operators must provide a specific code to link rollers and view what other users are performing on their displays. In large projects, roller operators are helped in connecting rollers, but this prevents the use of this function in smaller projects. Regarding the SD system, it does not yet offer this function. Therefore, roller operators assume IC systems are not helpful in terms of seeing how other roller operators work or in collaborating with other roller operators. According to roller operators, the connecting function in TCC does not always work well. They mention that they can see what their colleagues are doing, but it does not always match up with what they see in reality.

Roller operators value teamwork and communication with co-workers, and they recognize that learning from others' experiences can help them advance their own skills. They stated that they frequently observe what their co-workers perform and attempt to modify their own activities to match. Therefore, they aspire to a more accurate system.

"We should invest in a more precise and accurate system that allows us to do our job more efficiently."

Validation experts recognize the complexity of connecting rollers in HCQ and mentioned that this function is intended to be added for SD in a simpler manner. Regarding TCC, they clarified that the connection between rollers happens automatically. moreover, they identified potential causes for the decreased accuracy in TCC such as GPS signal interruption issues and data transfer delays between the rollers.

4.2.12 Effectiveness

Roller operators consider IC systems not helpful in achieving higher-quality asphalt. IC systems scored 2.16 on this point which can be indicated as dissatisfactory for roller operators. This is related to the following subject:

4.2.12.1Compaction quality and the functions of IC systems

Roller operators explained during the interviews that IC systems may not directly improve the quality of asphalt, but these systems can help ensure consistent compaction by monitoring the colour change on the screen. However, most roller operators mention that the quality of compaction also depends on various factors such as the asphalt mixture type and weather. These factors cannot be detected by the IC system.

Validation experts expressed the importance of the functions IC systems provide in achieving a higher quality of asphalt. However, the experts point out possible benefits from adding more functionality to the systems. They suggested that more dynamic and adaptive systems, such as systems that consider current weather forecasts and real-time data, could enhance compaction quality and thus produce asphalt of higher standards.

4.2.13 Performance Expectancy

Based on roller operators' insights, IC systems are not helping in saving time in daily work or even in making the work much easier. On this aspect, IC systems received a score of 2.23 on average, which is considered unsatisfactory for roller operators. This is related to the following subjects:

4.2.13.1 Time Saving Using IC Technology

Interview results have shown that even with the aid of technology, some parts of roller operators' tasks cannot be completed more quickly.

"Yes, you can't do it faster with what you have now. You just have certain steps that you have to take any way to get to the compaction."

Roller operators explain why IC systems are ineffective at accelerating work. They described how the usefulness of IC systems is constrained. As an example, IC systems are unable to monitor changes in surface and the existence of small spots on asphalt. Another example is the inability to see flatness with the naked eye particularly when working with various asphalt mixes where the degree of compaction varies.

Roller operators mentioned that in the future, particularly in cases when lab personnel are not available, it would be helpful to have a system that can scan the road and measure its compaction and flatness.

" We have relatively few laboratory technicians, so for example, no laboratory technician comes to measure on the bottom layer and intermediate layers, so if you could do that yourself from your own roller that you don't have to compact anymore, then yes, you save time."

In addition, roller operators emphasized the value of becoming capable of gauging the asphalt's depth and how that impacts how they operate. Roller operators think that having the temperature next to the depth of the asphalt would be a useful function for them to have.

"If you know that the layer is thick, then you know you can give it more time before compacting it but now it's always a bit of guessing and feeling."

The depth of the asphalt layer is significant in this situation since it can influence the amount of pressure that should be applied by the roller trough the operator. When the layer is slim, the operator must move swiftly to protect the asphalt. In contrast, if the layer is dense, the operator could utilize a longer time to roll the roller under pressure. Incorporating a depth measurement tool in IC systems could assist in streamlining the procedure of compaction and lower the possibility of damaging the asphalt.

Validation experts discussed the possible advantages of adopting a function that can automatically provide details regarding the state of the asphalt's surface and its depth. They stated that the roller operator might make better decisions throughout the compaction process with the aid of having such information available. However, validation experts doubt if such functions could help roller operators finish their work faster. They think that using IC technology in a more efficient way might result in time-saving.

4.2.13.2 Roller and Paver Communication in Terms of Speed

Roller operators indicate that a system that has a connection with the asphalt distribution machinery and displays the speed and temperature of the distribution machinery would be advantageous. Whenever the speed of the asphalt distribution machinery is raised, roller operators will be capable of regulating rolling speed and shortening rolling lengths.

"It would be nice to have a system in the roller that can communicate with the asphalt spreading machine. So, you can see the temperature of the asphalt spreading machine, and you can see how fast the machine is running. Then you know if the asphalt spreading machine is going faster, then you also have to go faster as well."

Validation experts emphasized the significance of the interaction between the paver and the roller. They stated that efforts are still being made to enhance the systems and provide efficient interaction between the paver and roller.

4.2.14 Effort Expectancy

IC systems received a 3.3 average on this factor, which is considered neutral for roller operators. Nevertheless, the following subject is raised in the interviews:

4.2.14.1 Knowledge of Advanced Functions in IC Systems

Interviews have shown that learning how to deal with basic functions such as the temperature and the number of roller passes was not difficult for roller operators. However, working with functions such as connecting two rollers or using ICMV as an indication for stiffness of the asphalt layer was totally unknown for most roller operators.

Validation experts acknowledged that some roller operators lack knowledge on how to operate specific features or functions of IC systems, which may limit their capacity for productive and efficient work. Better explanations and training are required for roller operators.

4.2.15 Perceived Enjoyment

IC systems scored 3.21 on this point which can be indicated as neutral for roller operators. However, the following subject is raised during validation sessions:

4.2.15.1 User Experience Improvement in IC Systems

Validation experts discussed the "gamification" term to increase the enjoyment factor associated with using IC systems. The experts stated that adding gamification components could improve user satisfaction and experience overall. The gamification concept refers to integrating game elements into non-game contexts (BI WORLDWIDE, 2023). Gamification's goal is to encourage people to interact with their data and receive a reward after finishing the assignment such as a badge or score (I. Andreev, 2023). The gamification concept could increase the sense of competition in a positive way between roller operators on site and thus increase the use of IC technology. According to validation experts, the gamification idea might be used in IC systems in the future.

4.2.16 Social Influences

IC systems received a score of 1.82 on average on social influences aspects which is considered unsatisfactory for roller operators. Roller operators do not feel that IC systems are promoted enough by individuals and the management to be used by roller operators. This is related to the following subject:

4.2.16.1 Lack of Communication and Trust

During the interviews, it was questioned whether management had encouraged roller operators to utilize IC systems. In their response, roller operators indicated that they were initially encouraged to use IC systems, but they felt later under pressure to use these systems.

“In the beginning, we were encouraged, but later on you actually feel a bit pressured. You have to use it”

However, a negative impact on encouraging the usage of IC systems could result from feeling compelled to use IC technology. Roller operators feel forced to use the system even though there are no explicit management requirements. This impression is brought on by the management notification that roller operators receive when IC technology is not turned on. Therefore, roller operators begin to feel in control and lose interest in using this technology. As a result, roller operators frequently turn on the systems but flip the IC system's screen instead of using the information.

“You don’t do it for yourself. You do it for the management. If you don't turn the system on, I receive a message from the manager to turn it on. The intention is that you have to use the system.”

"The company want to be able to see what you have done and that is the most important thing for the company. That's why we have the idea that these systems are for the people in the office, not for us."

Overall, turning on the IC systems is a regulation in the companies that makes roller operators feel forced to use these systems and these systems are only made for control of roller operators' work. Therefore, changing this idea for roller operators by explaining that the purpose of IC systems is to help operators seems essential. Besides, clarify that the purpose of analysing the data is to increase the work efficiency for future projects by learning from mistakes. Also, communicating with the operators about the results of the analysis could help to reinforce this idea since roller operators believe that being able to see the end result would help with motivation to use the system more often.

Another reason that roller operators tend to have no intention to use the IC systems is that roller operators become judged based on the results seen by management. To illustrate, it happens that sometimes roller operators make fewer roller passes in some areas and get less density value at the end. By correlating the density value of a specific spot with the number of roller's passes, the management usually thinks that the roller operators are responsible for that. In fact, roller operators acted in the mentioned spot with fewer roller passes for a reason as they mentioned in the interviews. For instance, in a weak place in a field where asphalt slides much, the roller operator must execute fewer rollers. Otherwise, it will completely be damaged.

Roller operators propose including a feature in the system that enables roller operators to make notes in the system regarding the state of the road or even remark on a specific area. The management could then recognize vulnerable areas or bad weather conditions that led to more or less compaction passes. Such details can be utilized to further evaluate and analyse previous activities.

Validation experts noticed the mistrust of roller operators in the management's motivations for putting the IC systems in operation. While management adopted the system to increase production quality, roller operators believe it is utilized for monitoring. There appears to be a lack of effective communication between management and staff regarding the goals and advantages of the systems, which results in misconceptions and a sense of being under control.

4.2.17 Facilitating Conditions

IC systems received a 2.44 average on this factor, which is considered unsatisfactory for roller operators. This is related to the following subjects:

4.2.17.1 Influence of Explanation and Training on the Use of IC Systems by Roller Operators

Interview results have shown that there was no training given to roller operators before using the IC systems in daily work. This issue is further investigated for each system during the interviews.

There was not a formal training program that lasted for a number of days, according to roller operators. Alternatively, they referred to explanations that covered subjects such as how to operate the system, how to log in and how to input information about the project. Roller operators shared the opinion that more thorough training sessions with practical application of the technology would be preferable, especially with regard to new employees. Inadequate training caused less intention to use IC systems by roller operators which resulted in less work efficiency.

"If something went wrong with the system during my work, I don't know what to do, I have in this case to call and wait for a solution."

Moreover, newer employees who started work after the purchase of HCQ have not even received any explanation on IC systems. These roller operators had to learn how to use HCQ from their colleagues. Therefore, it can be seen in Figure 12 that young roller operators are less satisfied only on this point compared to other roller operators.

"I haven't heard anything from the management about HCQ when I have been employed. I have been told about HCQ by a colleague."

Another roller operator mentioned the following:

"I've had to figure out how to use the system on my own since there was no manual, explanation or training provided."

Regarding SD, roller operators had no explanation, training, or manual on the use of the system except for some presentations about the system during a visit to the vendor's factory.

"We didn't get an explanation on how the SD system works, what we benefit from, or how to use this information, except for a factory visit. Training and good explanation are important."

However, SD is a new system and there is an attempt to introduce it in a proper manner to roller operators by connecting the system to old versions of rollers in multiple projects throughout the Netherlands and letting roller operators test the system.

Regarding TCC, there was also no proper explanation or training provided. It is still unclear for roller operators how to use the system. They have been provided with a single piece of paper in the roller cabin on how this system should be set up for registration. This gave most roller operators the feeling that this system was not for them but for the management.

"No explanation was given at all, nothing about that. Trimble was put in the roller cabin, you get an A4 paper with it. This is an on-and-off button you do this with this button. But No One has been with us to say, you should use it in this way… like this."

Nevertheless, the management has recently begun to pay more attention to IC systems according to roller operators.

Overall, roller users emphasise that making the technology easy to use requires training and a clear explanation in Dutch. As a part of the training, roller operators also suggest working with an actual system to comprehend it and splitting down the instructions into smaller components. In order to make a device easier to operate, they also highlight the potential of having instructions on the actual device or in a handbook. Additionally, a brief transition period between training and actual use is crucial. Plus, each button on the display needs to be elaborated. Finally, a description of the most typical issues that arise during use and instructions concerning how to fix them.

"Well, imagine your screen is not responding anymore. I know if my screen freezes, I can do a trick by turning off the split screen for a while and then turning it back on. But that, I learned myself."

The IC technology was introduced as validation experts mentioned. For staff members, the introduction was thought to be helpful. Nevertheless, the experts, emphasize the significance of sessions that address every aspect of utilizing the systems, including troubleshooting and hands-on training.

4.2.17.2 Assistance and support for IC System users

Roller operators are satisfied with the help they receive when they face a problem. The approach entails communicating with a contact person. This contact person is able to take action to address the issues roller operators face with IC technology. However, the contact person is preoccupied with other activities, and therefore it can be sometimes challenging to get a fast response. Roller operators mentioned that having a point of contact who can offer assistance more quickly would be more beneficial. Validation experts highlighted the value of technical assistance in increasing the usage of IC technology.

4.2.18 Use Recommendation

IC systems scored 3.28 on this point which can be indicated as neutral for roller operators. However, the following subjects were raised in the interviews:

4.2.18.1 Recommending IC systems for use

Interviews results have shown that roller operators are not convinced yet about the benefits of using IC systems in their daily work. Therefore, they are neutral regarding recommending IC systems use.

Validation experts stated that a number of elements, including the functionality of the system, push from firms, and the unknown advantages of IC technology by roller operators could affect roller operators' intention to use IC technology. Accordingly, enhancing the system's functionality and dealing with operators' concerns could result in greater acceptance and recommendations in the future.

4.2.19 Additional points

During the interviews, extra important topics were discussed with roller operators. These topics are the involvement of roller operators in the development of IC systems and in the decision-making of choosing a specific system before its actual use. The following paragraph represents a detailed explanation of these two issues:

4.2.19.1 User Involvement in IC Systems Development and Decision-Making

Regarding the involvement of users in IC systems development and in the decision to choose a specific IC system, roller operators indicated that they were not involved in such a process. They highlight the importance of including users in system development and requesting their input on what is required to be improved and what is currently effective. Additionally, roller operators stress the value of participating in the planning and decision-making processes for the use of specific technologies. From their perspective, these activities might reduce the issues with produced IC systems before they were made available on the market and could boost the rate at which roller operators use IC systems.

Roller operators mentioned that they usually been asked for feedback on different types of machinery, and they highlighted the importance of performing the same process with IC systems.

“If you have to work with it, then you have to test it first. So, if you can give your feedback on the system, that thing can make a lot of difference. For example, we went to Germany. I sat down on a new roller. I couldn’t put my feet on the ground. So, I indicated that, and they are now arranging something. So, imagine if you could do that with an IC system.”

Another point that roller operators touched on is the absence of discussion between the management and roller operators on the decision to adopt a specific type of IC system. Roller operators argue that they have been told that these systems are for them while they have not been asked on their point of view before the decision to adopt a specific type of IC technology.

“These systems are simply built in our rollers and not discussed with us.”

“Certainly if we have been asked about our preference between multiple systems, you feel more involved”

Validation experts emphasized the value of including end users in decision-making processes and taking their feedback into account when developing and improving systems. The conversations emphasized how important it is to satisfy user desires and expectations in order to improve the user experience as a whole and increase the rate of use.

4.3 Results validation

Results are validated internally with seven roller operators. Overall, roller operators have confirmed the results of the survey and interviews. Externally, validation experts expressed their understanding and agreement with the information provided in general. Participants in validation sessions found the focus group discussion valuable as it allowed them to reflect on their current practices and identify potential areas of improvement. A detailed explanation of the experts’ input was merged with each point of the research results in the interview results section above.

4.4 Results Summary

The surveys and interviews conducted in this study revealed multiple core and sub-issues related to the lack of utilization of IC technology. These core issues are presented in the following paragraphs. Besides, the sub-issues are grouped under the corresponding core issues. Table 7 and Figure 13 represent the core and sub-issues related to the lack of use of IC technology. The summary is followed by a SWOT analysis to indicate the potential future interventions by decision-makers.

Lack of knowledge of roller operators

The lack of knowledge among roller operators in terms of using IC technology includes several sub-issues such as difficulties in setting up a project before starting work, an inability to comprehend the functions of all buttons on the IC screen, and challenges in utilizing the advanced functions within IC systems such as ICMV indicator. These sub-issues may be attributed to the complex design which may not account for the limited knowledge of roller operators. Consequently, this results in reduced interaction with IC technology by roller operators and ultimately a lack of utilization of IC technology.

Furthermore, roller operators also lack the knowledge required to operate a system that does not support their native language. This sub-issue is closely related to the situation where technology designers may not have considered the roller operators' limited proficiency in foreign languages, given their educational background. This sub-issue also leads to decreased interaction with IC technology among roller operators, contributing to the overall lack of utilization of IC technology.

Considering IC technology as a registration system

Roller operators view IC technology as a registration system that does not offer valuable support for them. This issue involves several sub-issues as outlined below.

The first sub-issue concerns the inability to detect compaction value ICMV. This may be due to technology limitations in providing a function that can be relied upon for its precision where these functions fail in most of the investigated systems to provide an accurate indication for roller operators. Consequently, it results in reduced decision-making assistance for roller operators, leading to a lack of utilization of IC technology.

The second sub-issue involves the disability to record vibration activity in certain systems. This limitation could originate from certain machine suppliers not recognizing the potential benefit of such a function for roller operators. This also results in less helpfulness in decision-making support for roller operators and contributes to the overall lack of IC technology usage.

The third sub-issue revolves around the absence of support for factors such as mix type, weather, bitumen percentage, and depth. This shortfall may be attributed to technology limitations in providing more valuable support. Consequently, it leads to reduced effectiveness in achieving higher-quality asphalt and subsequently a lack of utilization of IC technology by roller operators.

The fourth sub-issue concerns roller operators' belief that IC technology does not help them save time during work. This perception may be due to a lack of training among roller operators in efficiently using IC systems. As a result, it diminishes performance expectations among roller operators regarding time savings contributing to their underutilization of IC technology.

The fifth sub-issue relates to the lack of enjoyment for roller operators while using IC technology. This issue could be attributed to IC technology being primarily designed for work purposes with limited consideration for providing an enjoyable experience.

Lack of trust in IC technology

The lack of trust in the information provided by IC technology involves three sub-issues.

The first sub-issue concerns the interruption of GPS signals when working in tunnels, between tall buildings or under trees. This led to the loss of machine tracking on the IC screen. This issue may be caused by shortcomings in GPS technology resulting in signal loss. It distracts roller operators during their work and contributes to their underutilization of IC technology.

The second sub-issue relates to unregistered offset movements in some systems causing confusion among roller operators. This issue could be attributed to certain machine suppliers who may not have considered the potential benefits of such a function for roller operators. It distracts roller operators during their work leading to a lack of use of IC technology.

The third sub-issue involves doubts regarding the accuracy of temperature readings. The temperature accuracy might be influenced by factors such as wind or interference from other machine parts on the temperature sensor. This issue could be caused by technology limitations in accounting for external conditions like wind. It reduces the effectiveness of decision-making for roller operators and consequently leads to their underutilization of IC technology.

Lack of information transfer between the crew on site

The issue of lacking information transfer between the on-site crew includes three sub-issues.

The first sub-issue involves the inability to determine the temperature behind the asphalt paver and the speed of the paver. This problem could be caused by technological limitations in establishing a connection between the roller and the paver. Consequently, it results in reduced assistance in identifying interesting information during the compaction process leading to the underutilization of IC technology.

The second sub-issue concerns the difficulty of connecting rollers, possibly formed by complex design that does not consider the limited knowledge of roller operators. This issue leads to reduced collaboration among roller operators during their work and results in a lack of IC technology utilization.

Lack of communication between the management and roller operators

The issue of insufficient communication between the management and roller operators involves three sub-issues.

The first sub-issue concerns the lack of communication regarding the data registered by IC systems. This issue may be caused by the difficulty in analysing the data recorded by IC systems. Consequently, learning from the recorded data is difficult which makes IC systems fewer instructive systems that lack the ability to assist roller operators in improving their skills, leading to the underutilization of IC technology.

The second sub-issue revolves around the mandatory requirement for roller operators to turn on IC systems during work. This requirement may be necessary to collect data for analysis by management, enhancing work efficiency and learning from mistakes. However, this obligation has the unintended consequence of discouraging roller operators from using IC systems.

The third sub-issue relates to the exclusion of roller operators from the development of IC systems and the decision-making process when selecting a specific system for actual use. This issue could be caused by systems being designed from a technological perspective rather than an end-user perspective. This results in social influence among roller operators, where most choose not to use IC technology.

Table 7 Core and sub-issues

Core issue	Related sub-issue	Cause of sub-issue	Effect of sub-issue
1. The lack of knowledge.	4.1.1 Systems language.	Machine suppliers might not consider the operators' lack of knowledge of foreign languages.	Cause less interaction with IC technology by roller operators.
	4.1.2 Setting up a Project.	A complex design that might not consider the limited knowledge of roller operators.	Cause less interaction with IC technology by roller operators.
	4.1.3 Buttons functions.	A complex design that might not consider the limited knowledge of roller operators.	Cause less interaction with IC technology by roller operators.
	4.14.1 Advanced functions.	A complex design that might not consider the limited knowledge of roller operators.	Less effort expectancy (learning how to use is difficult and becoming skilful in use is also difficult)
2. IC is seen as a registration system that cannot provide valuable support.	4.8.2 Disability to detect compaction value.	Technology shortcoming.	Not helpful in decision-making.
	4.8.5 Vibration is not Recorded in some systems.	Some machine suppliers might not consider that such a function could benefit roller operators.	Not helpful in decision-making.
	4.12.1 No support regarding mix type, weather, bitumen percentage and depth.	Technology shortcoming.	Less effective technology.
	4.13.1 Finishing work faster.	Roller operators were not educated on the efficient use of IC systems.	Doesn't support performance expectancy (save time).
	4.15.1 Normal use enjoyment.	Typical system that is designed for work only.	Less enjoyment using IC systems.

3. Lack of trust in the information provided by IC technology.	4.6.1 GPS signal interruptions.	Technology shortcoming.	Roller operators become distracted.
	4.6.6 Offset movement is not registered in some systems.	Some machine suppliers might not consider that such a function could benefit roller operators.	Roller operators become distracted.
	4.8.3 Temperature reading accuracy.	Technology shortcomings. (It does not take other conditions into account such as wind).	Not helpful in decision-making.
4. Lack of information transfer between the crew on site.	4.9.1 The temperature behind the paver is unknown.	Technology shortcoming.	Not assistive systems.
	4.11.1 Difficulty of connecting rollers.	Technology shortcoming.	Not help in collaboration.
	4.13.2 Paver speed is unknown.	Technology shortcoming.	Doesn't support performance expectancy (become more skilful).
5. Lack of communication between the management and roller operators.	4.10.1 Lack of communication on registered data.	the difficulty of analysing the data registered by IC systems.	Non-instructiveness system.
	4.16.1 The mandatory turn-on of IC systems.	Data needed for analysis.	Less promotion for the use of IC systems.
	4.19.1 Non-involvement in the development and decision-making.	Systems are designed from a technology perspective, not from the end-user perspective.	Social influence 2 (individuals not using IC).

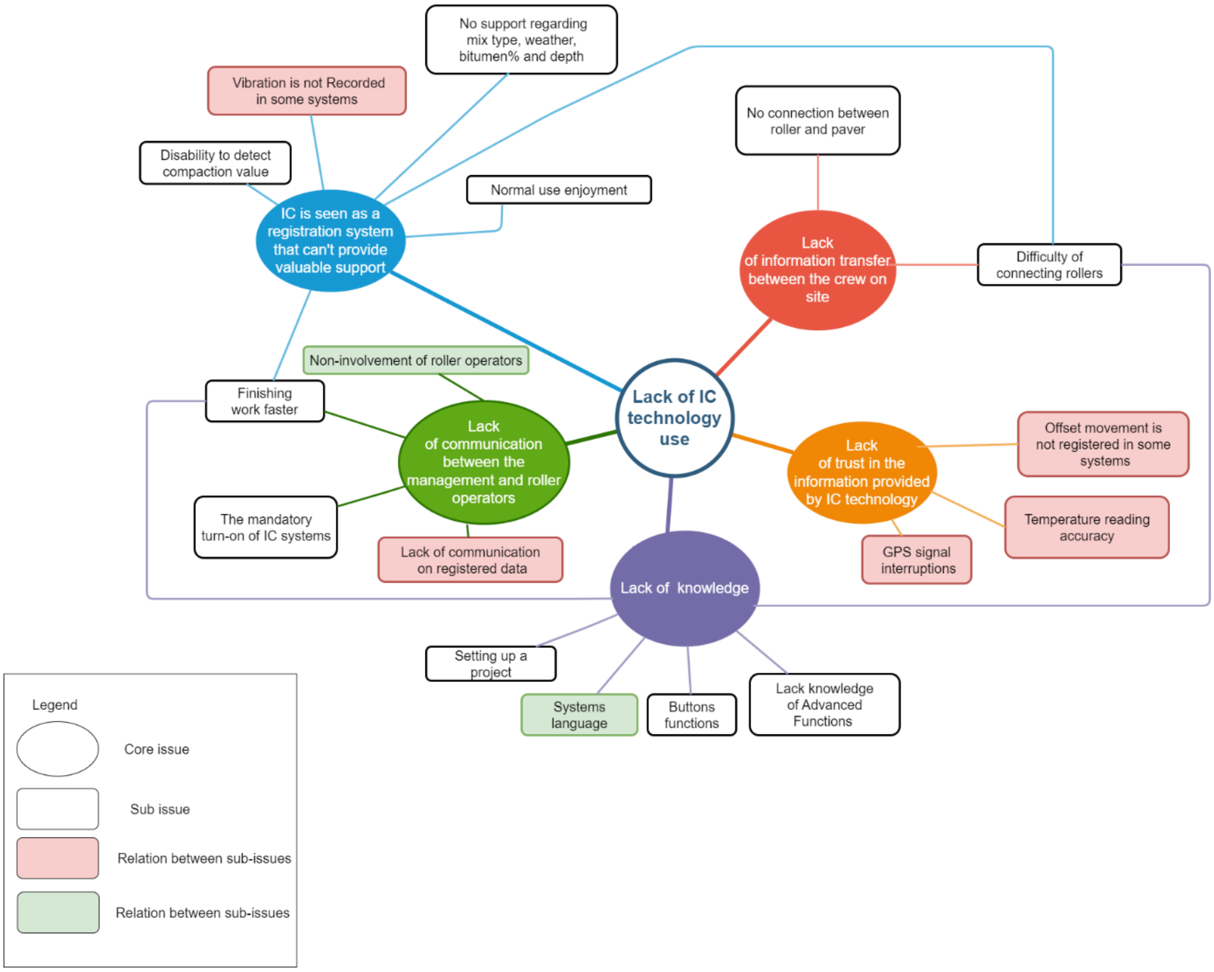

Figure 13 Core and sub-issues

4.4.1 SWOT Analysis

In order to categorize the issues raised in the results section, a SWOT analysis is used. SWOT allows dividing the related issues into Strengths, Weaknesses, Opportunities and Threats and assists in developing strategic goals (KENTON, 2023). Table E in Appendix C shows the categorization of results into 4 SWOT categories. It has been assumed that strengths are the advancement of technological and social aspects related to the use of IC systems, and Weaknesses are the shortcomings that require further research to be solved. Opportunities are the shortcomings where less effort and time need to be solved. Threats are the points that could threaten the use of IC systems in the future. SWOT analysis can be used in the future by decision-makers for strategic planning.

5. Discussion

Based on the research problem, there is a lack of IC technology use by roller operators and previous investigations lack focus on their user experience. This research thesis utilized a method that combines technical and non-technical aspects with a special focus on the end-user perspective to investigate the barriers faced by roller operators in their daily work. This resulted in core and sub-issues related to the use of IC technology as can be seen in Table 7 and Figure 13. Both core and sub-issues are discussed in this chapter. Furthermore, the connections between the results and to literature are indicated. Finally, the validation process is discussed, and research limitations are highlighted.

5.1 Core and Sub-issues

As a result of summarizing the results in the previous chapter, multiple issues were raised for discussion. These issues are as follows.

Knowledge Level of Roller Operators.

Roller operators to a large extent have no knowledge about the advantages of using IC systems in asphalt compaction. Researchers' understanding of the benefits of using IC technology and roller operators' understanding of those benefits diverge. In addition, roller operators lack the knowledge to operate with some advanced functions in IC technology such as connection two rollers or using the ICMV indicator.

The lack of knowledge of roller operators starts from the fact that roller operators were not educated to use these systems during their education program to become roller operators. Thus, the problem starts with the education of roller operators. Therefore, incorporating IC technology in the education program of roller operators could produce a new generation of roller operators able to use IC technology in an efficient way. In fact, the new generation of roller operators could be the most suitable targeted category to focus on to increase the use of IC technology among them since the results of this study have shown the young generation of roller operators is more open to using IC technology in their daily work.

Nevertheless, to tackle the current lack of use of roller operators who already finished their education program, training should be provided for employed roller operators in companies. Training should include a clear explanation in Dutch, working with an actual system to comprehend it and splitting down the instructions into smaller components. In addition, each button on the display needs to be elaborated. Plus, a description of the most typical issues that arise during use and instructions concerning how to fix them. Lastly, a brief transition period between training and actual use is crucial to maintain the gained knowledge.

To support building knowledge in the education programs and training in companies, simplifying the interaction with IC technology by the machine supplier for roller operators seems essential in this regard. For instance, connecting two rollers could be made automatic with one button on the roller operator's screen. Simplifying the interaction with IC technology functions by machine suppliers based on roller operators' education level could allow more promotion of IC technology use among roller operators.

Beneficial Extra Functions to IC technology

Results have shown that adding some functions to IC technology could help roller operators more in their work such as weather forecasting and measuring the depth of asphalt. This requires incorporating such functions in IC systems by machine suppliers. However, this necessitates further research by researchers on developing such functions in collaboration with machine suppliers. On top of that, the feasibility of adding these functions should be further researched. There should be a balance between adding functions and maintaining less level of confusion for roller operators.

Furthermore, increasing the normal enjoyment of using IC technology for roller operators could play a significant role in promoting the use of IC technology. The enjoyment feeling of using IC technology could increase the interaction between IC technology. This can be done by incorporating the gamification concept of IC systems for instance.

Technical issues in current Functions of IC technology

Multiple technical issues in IC technology have been indicated in the results. These issues require solutions to increase the trust in IC technology among roller operators.

One of the important technical issues is the disability of IC technology to detect the compaction value which could help roller operators to know when to stop compaction. Although IC technology can give an indication of the ground stiffness (ICMV), this function is less accurate in asphalt pavement, works only when the roller is vibrating and there is difficulty in correlating this value to the actual density of asphalt. In addition, the manner of utilization of this function by most roller operators is unknown.

Researchers have been working on alternative ways to help roller operators in this regard. They could verify a unique technique for estimating asphalt pavement density on site (Kassem et al., 2015). This technique utilizes the compaction curves for each roller and the position of the roller on the asphalt mat to forecast the asphalt density. The compaction curve represents the relation between the moisture content and the density of asphalt.

Kassem et al., (2015) validated the developed method in the field. The findings demonstrated a good correlation between anticipated and actual densities. This function could be used to increase the functionality of IC systems in the future. However, this function is not implemented yet in practice for multiple reasons. First, this technique necessitates the existence of compaction curves per roller, the compaction sequence and the distribution of compacting forces within each roller (Kassem et al., 2015). In addition, the compaction curve is usually determined in the laboratory and varies for each asphalt mix. These matters constitute an obstacle to applying this technology in reality.

According to the authors, commercial companies could improve the developed function further to become dependable in the field. The authors could create and test new systems in a pilot setting, but they need support from companies to assist in the development of this function and thus the full execution in the field. This emphasises the importance of more cooperation between researchers and machine suppliers in the development of this function and IC technology.

Other issues in IC technology such as the language issue, the disability to record the vibration activity in some systems, the interruption of GPS signal, unregistered offset movement in some systems and the accuracy of temperature readings lead to less use of IC technology by roller operators.

All previously mentioned functions could add value to the support provided by IC technology and thus increase the usage rate of this technology among roller operators. Therefore, machine suppliers need to fix these issues or incorporate an alternative technology that could provide the same function. In this regard, the knowledge in recent research could help boost the development of IC technology if machine suppliers use it.

Connection between rollers and between the roller and the paver

Results have shown that roller operators face difficulty in connecting two rollers in some systems. This has an influence on the collaboration between roller operators during their work. The roller operator will not be able to see the location of another roller on his screen and the number of passes the other roller did in a specific area. This could lead to multiple passes by multiple rollers on a specific area. This could result in more effort, time, and cost. This issue requires simplifying the connection process for roller operators by machine suppliers.

Another significant issue identified in the results is the wish of roller operators to have the temperature readings behind the paver. In fact, having the temperature readings only at the location where the roller moves and not for the whole asphalt mat is not practical for roller operators while having the temperature behind the paver in real time could help roller operators to adjust their compaction strategy. However, current IC systems do not interface with the paver. This could be related to the complexity of transferring the temperature reading from the paver to rollers. The operation of calculating or predicting the cooling of the asphalt mat at different timings and locations during the movement of the paver is challenging.

The technology that can measure the temperature across the entire surface is introduced in research done by (Makarov et al., 2020). This research could provide a model to predict the temperature of asphalt mats at different timings and locations as can be seen in Figure 14 below. this emphasizes again the need to use research knowledge by machine suppliers in the development of IC technology.

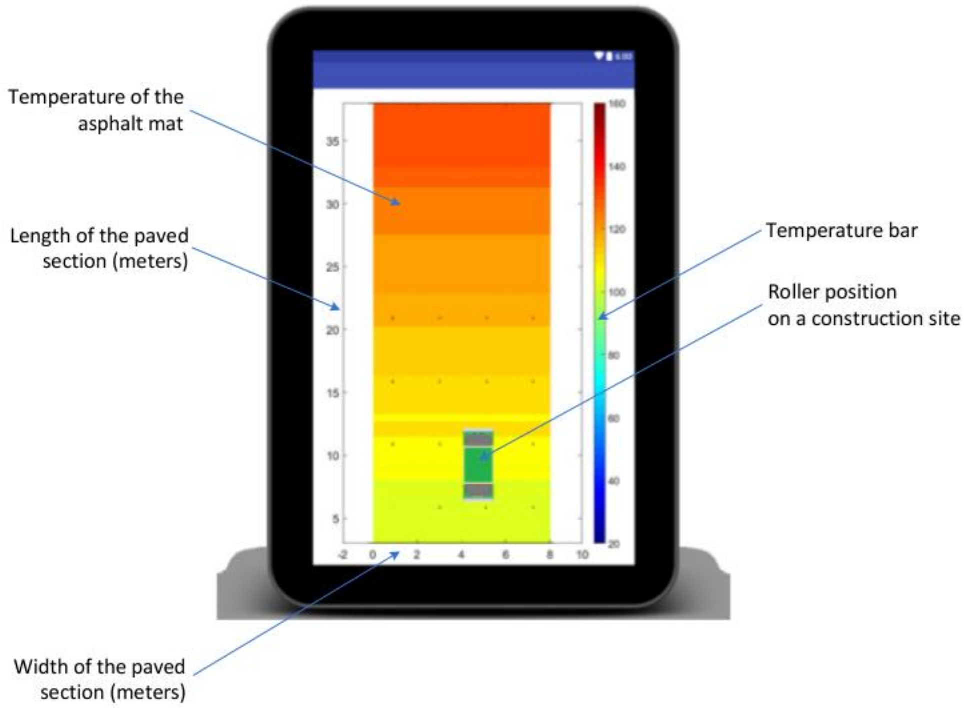

Figure 14 Temperature readings across the entire asphalt mat (Makarov et al., 2020)

Communication with roller operators

Several technical and non-technical issues embedded in results have a relation to the communication with roller operators. Starting with the technical pat, two issues are highlighted in the results. First, the belief of roller operators that IC technology does not help them save time during work has to do with the lack of communication between the management and roller operators. To illustrate, recent research has shown that IC systems have potential time-saving. Juma, (2023) reported that the use of IC systems during asphalt compaction results in a reduction of gas use compared to conventional compaction. That means compaction with IC systems requires a shorter time. Therefore, there is time-saving in the process. This information needs to be known to roller operators through the management. This could play a role in changing their belief and thus increasing the intention of roller operators to use IC technology more frequently.

Second, the lack of communication on registered data by IC systems is in fact effected primarily by the difficulty of analysing the data. This is caused by multiple factors such as the imperfections of the registration, the lack of easy-to-use analyse-algorithms and in general the complexity of the matter. This requires developing an easy-to-use analysis tool and communicating the data registered by IC systems.

Moving to non-technical issues related to the communication with roller operators, the results revealed two important issues in this regard. The first issue is the mandatory turn-on of IC systems by roller operators. This issue makes roller operators feel controlled by the management while the request by the management to turn-on on IC systems is to be able to enhance the process of compaction as validation experts mentioned. Therefore, this requires effective communication between the management and roller operators to clarify that the purpose of the obligation of turning on the systems is to enhance work efficiency at the end and not for control.

The second non-technical issue is the non-involvement of roller operators in the development of IC systems and in the decision-making to choose a specific system before bringing it to actual use. This issue leads to a failure to benefit from the operators' experiences in boosting the developing IC technology. Also, it prevents the management from using roller operators' experiences in choosing the most suitable system that can provide sufficient support before purchasing a specific system. Therefore, involving roller operators in the development of IC systems and in the decision-making to choose a specific system before bringing it to actual use seems significant.

5.2 Relations between issues in Results

Some sub-issues connected to a specific core issue could have also a relation with another core issue as can be seen in Figure 13. For instance, the sub-issue regarding saving time using IC technology has a relation with the lack of knowledge of roller operators. In other words, finishing work faster requires comprehensive knowledge of the use of IC systems. Without that knowledge, it will not be possible to finish work faster. On top of that, finishing work faster requires an illustration from the management on the recent research done on the ability of IC technology to save time during work. Here the importance of communication between the management and roller operators comes to the top.

Moreover, the sub-issue of difficulty of connecting rollers is also related to the lack of knowledge of roller operators to perform this step in the IC systems that offer this function. Besides, the same sub-issue has an influence on considering IC technology only registration technology that cannot provide valuable support for roller operators.

Further, some sub-issues have a relation as can be seen in Figure 13. For instance, the sub-issue inability to record the vibration activity in IC systems, GPS signal interruptions, the inability to register offset movement in some IC movements and the inaccurate temperature readings by sensors have all been related to the lack of communication on the registered data by IC technology. All mentioned sub-issues have a negative effect on the communication of the registered data since these sub-issues will lead to missing data required for the analysis which leads at the end to inaccurate analysis of the data.

Another representation of the connection between the sub-issues is the relation between the non-involvement of roller operators in the development of IC systems and the sub-issues difficulty with foreign system language. To illustrate, if the management asks roller operators for feedback on the use of IC systems such sub-issue will be known to the management and could be transferred to the machine supplier of IC systems to solve such issues. This also will enhance the communication between the management and roller operators and help to form a feedback circle between the management, roller operators and machine suppliers.

5.3 Connection of Results to Literature

Research in the field of IC technology lacks investigations on the lack of use of IC technology by roller operators. However, research that targeted other group than roller operators to investigate the lack of use of IC technology has been found. This research will be discussed to highlight the similarities and differences in the output compared to this study. The research is "Suitability of Intelligent Compaction for Asphalt Pavement Quality Control and Quality Assurance" done in 2018 by Yoon et al., (2018).

Next to the focus of the research on the viability of using IC technology for quality control and assurance in asphalt compaction, this research also investigated the adoption of IC technology by Departments of Transportation (DOTs). DOTs are state agencies responsible for the quality assurance of road pavement in the USA.

The research results have shown that multiple issues played a role in the lack of use of IC technology by DOTs as can be seen in Figure 15 below.

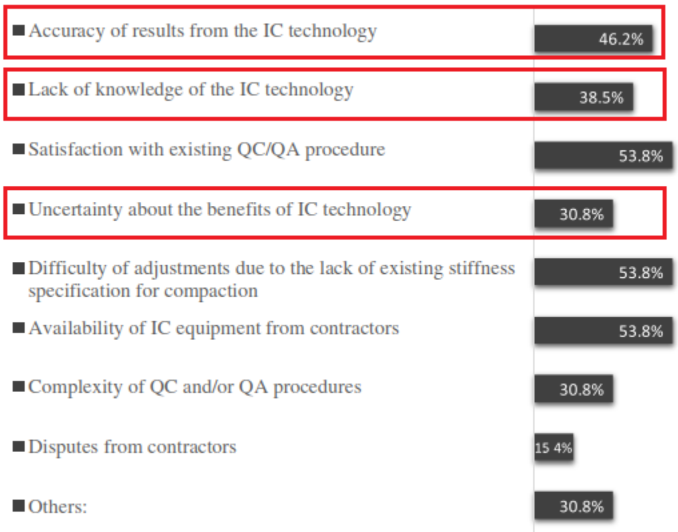

Figure 15 the reasons behind the lack of use of IC technology by DOTs in the USA (Yoon et al., 2018)

Looking at the similarities between Yoon et al., (2018) research and this study, it can be seen that both studies resulted in three similar barriers related to the use of IC technology. These similar barriers are indicated with red borders in Figure 15.

The first similar barrier is the accuracy of the results of IC technology. The accuracy of IC systems is indicated in the results of this study. Roller operators as well as validation experts touched on the results of problems with the accuracy of temperature sensors and GPS accuracy on the results obtained by IC systems. The second similar barrier is the lack of knowledge of IC technology. The same issue is also indicated in this study during the interviews with roller operators. The last similar barrier is the uncertainty about the benefits of IC technology. This study has shown that roller operators have doubts about the added value of IC technology to their daily work.

The research done by Yoon et al., (2018) highlighted issues from the DOTs organizations and the machine vendors perspective while this study focused on the perspective of the end users of IC technology. Although the group targeted in the research of Yoon et al., (2018) is different, still some issues match in the two studies. However, focusing on the end-user perspective leads to a more comprehensive understanding of the issues related to the use of IC technology and a more in-depth explanation of the causes of these issues.

Further, some specific issues that came to the top in the results of this study are touched on in previous research. Table 8 below shows some issues highlighted in this study and how these issues are related to corresponding issues mentioned in previous research. This provides a confirmation of the results of this study and makes a clear statement that the issues mentioned in research since 2007 are still present nowadays and require a solution.

Table 8 Issues highlighted in this study and previous research

The issue highlighted in this study	Corresponded issue in previous research	Connection between the two studies
4.12.1 Compaction quality and the functions of IC systems.	It is recommended to analyse whether there are any additional sensors must be installed that collect data about other aspects that influence the asphalt processing process such as the meteorological factors of wind, precipitation, solar radiation and temperature (Simons, 2007).	Roller operators miss more valuable support in IC systems.
4.16.1 Lack of Communication and Trust between roller operators and the management.	The main criticism is that it is possible for the boss to remotely monitor the work performed (Simons, 2007).	Roller operators feel that IC systems are made for the management and not for them.
4.10.1 The Use of Recorded Data in IC Systems.	The results of the work performed by asphalt teams are not feedbacked (de Man, 2007).	Lack of communication between the management and roller operators.
4.19.1 User Involvement in IC Systems Development and Decision-Making.	The capabilities of the asphalt processing teams are used to a limited extent. This is caused by limited communication between the team and the organization (de Man, 2007).	The team can contribute to enhancing work efficiency by giving feedback on working processes and systems used in these processes if their capabilities are used in the right manner.

5.4 Validation Process

The validation sessions have offered a confirmation, correction, and addition for the results. However, some specific points need to be discussed. First, roller operators have shown a lack of knowledge of specific functions that IC systems can offer. These functions were totally unknown to roller operators. This emphasises the need to educate roller operators on the support and functions that IC systems can offer. Second, the experts mentioned removing some functions in the new systems while roller operators might consider the current systems to have limited functionality. Therefore, such points need further investigation and research in collaboration with roller operators. Finally, validation experts discussed the dependence of IC systems on the technological advancement of the parts that the technology consists of such as the GPS component. The machine supplier might want to solve such an issue among multiple issues, but he is dependent on technology advancement as well.

5.5 Research Limitations

This study aimed to investigate the use of IC technology in road construction by end users which are the roller operators. During and at the end of the research, multiple limitations were raised for discussion. These points are as follows.

The plan was to involve small construction companies as well to get the perspective of roller operators working in these companies since the organization of big and small companies may differ. In addition, the researcher was planning to involve more big construction companies since some of these companies use other types of IC systems. Including more small and big construction companies could give the researcher the opportunity to highlight more issues related to the use of IC technology. The researcher had the chance to involve these types of companies through the Aspari network but not all Aspari companies were open to participating in the research for unknown reasons.

Furthermore, the research was done during a busy period of construction work which made contact with roller operators difficult and the time to speak to them was limited. Choosing roller operators for interviews based on specific categories was logistically impossible as well because of the high workload in most work sites. Therefore, implementing further research in this field in a period where less work is going on could be more rewarding.

Lastly, the significance of the survey results has been examined. Nevertheless, the relatively small sample size could have an influence on the significance of the results. Therefore, further research with a larger sample size might offer more accurate results.

6. Conclusion

The research problem indicated a lack in the use of IC systems by roller operators and a lack of investigations that focus on the roller operators' perspective. This study addressed the issue of focusing on the end-user perspective by developing a research method that could investigate the difficulties that roller operators face in their daily work in relation to the use of IC systems. Additionally, the research method could indicate the reasons behind these difficulties and the viable solutions to tackle these difficulties.

In conclusion, the lack of use is caused by multiple core barriers such as the lack of knowledge of roller operators and the lack of valuable support provided by IC technology. Roller operators have explained in detail these barriers in the interviews. They gave reasonable reasons for these barriers such as the lack of training and the limitations IC technology has. Moreover, roller operators proposed solutions for these barriers based on their experience such as the functions they find valuable to be added to IC technology and the requirements for the training they need. Generally, improving the system's features and addressing operators' concerns could lead to higher acceptance and use of IC systems by roller operators.

Further, results have shown that roller operators are more dissatisfied with the social aspects than the technological aspects in relation to the use of IC technology. This highlights the fact that the IC technology is not introduced to roller operators in a satisfactory manner. In addition, results have shown that young roller operators who have up to 10 years of experience are more open to the use of IC technology in their daily work. This could be related to the fact that the younger generation is more familiar with using technology in daily life.

Furthermore, connecting this study to previous research, it has been seen that some issues such as the lack of communication between the management and roller operators have been present since 2007.

Overall, this study highlighted important aspects regarding the use of IC technology in the Netherlands such as the importance of communication between the management and roller operators and the significance of roller operators' involvement in the development of IC systems and decision-making. The results of this research thesis could provide comprehensive answers to the preliminary research questions as follows.

1. What are the difficulties associated with the lack of use of IC systems among some roller operators?

> The technological and social barriers indicated in the results give an answer to question one. There are multiple core difficulties raised in the results of this study. Some of these difficulties are related to the IC technology and the other part are related to the social aspects in relation to the use of IC technology. However, the core difficulties indicated in this study regarding the IC technology itself are first, the lack of knowledge of roller operators about what the IC technology can offer if it is used in the right manner. Second, IC technology is seen as a registration system by roller operators that cannot provide valuable support for them. Third, there is a lack of trust in the information provided by IC technology. Fourth, there is a lack of information transfer

between the crew on site. Fifth, there is a lack of communication between the management and roller operators.

2. What are the reasons that cause these difficulties?

The reasons behind these barriers indicated in the results shape an answer to question two. First, the lack of knowledge can be seen because of the lack of training given to roller operators. Second, roller operators consider IC technology a registration system because of the lack of IC systems' ability to provide comprehensive support in decision-making for roller operators. Third, the lack of trust has resulted from the fact that the technology has limitations in providing full accurate information. Fourth, the lack of communication between the crew on site is caused by the fact that IC technology fail to communicate with other machinery onsite. Fifth, the lack of communication between the management and roller operator is because data registered every workday by IC systems is kept by the management and either analysed occasionally or not analysed at all.

3. How can the difficulties be addressed to expand the use of IC systems among roller operators?

The suggestions provided by roller operators to tackle the barriers they face in the results section form an answer to question three. First, the lack of knowledge could be solved by comprehensive training provided to roller operators. In this way, roller operators will be able to use all system functions efficiently and deal with technical problems that come across during the use of IC technology. Second, more valuable functions such as the function that helps roller operators to predict weather conditions and measure the asphalt depth could be added to IC technology to help roller operators make better decisions during their work. Third, search for available technology advancement that could solve the technical issues IC technology faces. Fourth, the lack of communication between crew on site could be solved by developing a system that can connect the asphalt paver with the roller. In this case, the roller operator will be able to adjust his speed based on the speed of the paver and compact the asphalt within a suitable temperature. Fifth, the communication between the management and roller operators could be enhanced by analysing and communicating the data registered regularly with roller operators and giving them feedback on their work process.

Summary

The difficulties associated with the lack of use of IC technology, the reasons that cause these difficulties and the suggestions to address these difficulties are summarized in Table 9 below.

Table 9 Outcomes Summary

#	Difficulties associated with the lack of use of IC technology	The reasons that cause these difficulties	Suggestions to address these difficulties
1	The lack of knowledge of roller operators about what the IC technology can offer if it is used in the right manner.	Lack of training given to roller operators.	Providing roller operators with comprehensive training.
2	IC technology is seen as a registration system by roller operators that cannot provide valuable support for them.	Lack of IC systems' ability to provide comprehensive support in decision-making for roller operators.	More valuable functions should be added to IC technology to help roller operators more in decisions making during their work.
3	There is a lack of trust in the information provided by IC technology.	The technology has limitations in providing full accurate information.	Search for available technology advancement that could solve the technical issues IC technology faces.
4	There is a lack of information transfer between the crew on site.	IC technology fails to communicate with other machinery onsite.	Developing a system that can connect the asphalt paver with the roller.
5	There is a lack of communication between the management and roller operators.	Data registered every workday by IC systems is kept by the management and either analysed occasionally or not analysed at all.	Communicating the data registered regularly with roller operators and giving them feedback on their work process.

7. Recommendations

7.1 Recommendations

The recommendations developed in this chapter are based on the previous knowledge gained from results, discussion, and conclusion. The recommendations below represent an answer to the main research question which is “How can the use of intelligent compaction technology be expanded among roller operators in the Netherlands?”

- **Making the training obligatory for roller operators**

  To solve the lack of knowledge of roller operators, giving training for roller operators before the actual use of rollers could have a significant effect on increasing the use of IC technology by roller operators. As requested by roller operators, training should involve working with an actual system in order to comprehend it and splitting down the instructions into smaller components, each button on the display needs to be elaborated, having instructions on the actual device or in a handbook and finally, a brief transition period between training and actual use is crucial. Next to training roller operators in companies, the training of roller operators in education institutes should obligated as well. This can be facilitated by including digital technologies such as IC technology in the education program of roller operators. In this way, it can be guaranteed that roller operators who recently graduated come with sufficient knowledge to work with these systems.

- **Incorporating more valuable functions in IC systems**

  To change the idea that IC systems are registration systems, and these systems cannot provide valuable support for roller operators, the following needs to be done. First, more valuable functions could be added to solve this issue. An example of these functions is the ability of IC technology to predict weather conditions, measure compaction value and receive temperature readings of the whole asphalt mat. These functions require further research and development. Therefore, more collaboration between researchers in this field and machine suppliers is required. Machine suppliers should use recent knowledge in research in the development of IC technology. This also requires involving roller operators in the development of IC systems. In this way, the researchers and machine suppliers could know the exact up-to-date wishes of roller operators and use the expertise of roller operators in the development of IC systems. Such a step could reduce the problems with produced IC systems before they are made available on the market and could boost the rate at which roller operators use IC systems.

  Second, making IC systems enjoyable to use. This can be done by incorporating the gamification concept in IC systems. This could improve user experience and satisfaction and increase the use of IC technology significantly.

- **Solving technical issues**

  To tackle the issue of lack of trust in the information provided by IC technology, research needs to be done on the available technology advancement to solve IC technology limitations such as temperature readings accuracy and GPS signal interruptions. Improving the system's features and addressing operators' concerns is expected to lead to higher acceptance and use of IC systems by roller operators. On top of that, the interaction with IC systems should be made simple and straight and in line with the education level of roller operators. This can be done by simpler design that can be understandable by roller operators.

- **Enhancing the communication between crew on-site**
  To solve the issue of lack of information transfer between the crew on site, there is a need to develop a system that can connect the asphalt distribution machinery with site rollers and display the speed of the paver and the temperature of the asphalt mat behind the paver. For this purpose, the recent knowledge in research could be used by machine suppliers. In this way, roller operators will be capable of regulating rolling speed according to temperature and shortening rolling lengths. In addition, connecting rollers with each other should be simplified for roller operators by making the connection automatically for instance.

- **Organizing regular sessions for roller operators by management**
  To tackle the issue of lack of communication between the management and roller operators, sessions could be organized by the management on a regular basis. The purpose of these sessions is to communicate the data registered by IC systems regularly with roller operators. This requires explaining the mistakes that happened during work and how they can be learned from and avoided in the future. Communicating the results registered by IC systems and giving roller operators regular feedback on their performance could improve the roller operators' skills in using IC systems and thus increase work efficiency. It could also help to change the idea that IC systems are made only for management. However, further efforts are required to develop an easy-to-use data analysis tool.

  Moreover, the management could use these sessions to explain the advantages of using IC technology by showing recent research in this field. An example of these advantages could be recent research that shows that IC technology helps to finish work faster. Such examples could motivate roller operators to use IC technology more frequently.
  Furthermore, a part of these sessions could be used to gather feedback from roller operators on their experience using IC technology. This feedback is important to identify the drawbacks of IC systems. This feedback can be transferred regularly to machine suppliers so that they can find a solution for these drawbacks. Such a step can be considered as the first step to involve roller operators in the development of IC technology. This also will make the development of IC technology faster.
  Finally, roller operators could be asked to test multiple IC systems in the early stage of the decision to purchase a new IC system. Roller operators could in this way indicate the drawbacks of each system available in the market and give advice on the better system to adopt. This would allow roller operators to play a positive role in decision-

making. This also will make the company adopt the best system which leads to better quality of work and thus less cost.

7.2 Recommendations for Further Research

To address the limitations of the current study on IC technology use in road construction by roller operators, future research should consider the following. Firstly, investigate the perspectives of roller operators in small construction companies, comparing them with those in larger organizations to understand potential variations. Additionally, conducting research during less busy construction periods facilitates more in-depth interviews and provides richer insights. Moreover, expanding the sample size among roller operators. This could enhance the statistical significance of the findings. These suggestions aim to broaden the study's scope, improve industry representation, and strengthen the generalizability of results.

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Appendix A- Usability Typical Parameters

Table A Usability typical parameters (Makarov et al., 2021)

Parameter	**Question**	**Score**
Reusable	The provided support encourages you to interact with it frequently	Score 1 to 5 where: 1- Completely disagree. 2- Disagree. 3- Neutral. 4- Agree. 5- Completely agree.
Clear	The provided support provides clear information	
Comprehensible	The provided support uses understandable visuals	
Easy to use	The provided support provides information that is easy to follow	
Actionable	Looking at the provided information, you know what you need to do	
Non-overloading	The provided support does not overload you with information	
Non-distractive	The provided support provides you with information in a non-distracting manner	
3D visualization	You would rather have the information in 3D	
Helpful	The provided support helps in the decision making	
Assistive	The provided support helps to find points of attention in the operation	
Instructive	The provided support helps improve your skills	
Informative	The provided support helps improve your knowledge about asphalt operations	
Explicative	The provided support helps see how other operators are working	
Collaborative	The provided support helps collaborate with other operators	
Effective	The provided support helps achieve higher-quality asphalt	
Supportive	The provided support helps make faster decisions about your strategy	
Recommendable	You recommend the use of the system	

Table B UTAUT & TA typical parameters (Watkinson et al., 2021)

UTAUT Construct	Survey Items
Performance Expectancy	HIE has saved me time at work
	HIE has made my job easier
	Using HIE helps me to be a better healthcare provider
	Using HIE supports critical aspects of my patients' healthcare
	Using HIE enhances my effectiveness as a healthcare provider
	Overall, HIE is useful to me in managing my patients’ healthcare
Effort Expectancy	Learning how to use HIE was easy for me
	It was easy for me to become skilful at using HIE
	I find HIE easy to use
Perceived Enjoyment (ENJ)*	HIE is enjoyable to use
Job Relevance (REL)*	In my job, using HIE is important
	The use of HIE is pertinent to many of my job-related tasks
Habit (HT)	The use of HIE has become a habit for me
Behavioural Intention (BI)	I intend to use HIE regularly
	I intend to increase the amount I use HIE in the future
Social Influence	People in my workplace promote the use of HIE
	People who influence my behaviour at work use HIE
	Most individuals in my workplace use HIE
Facilitating Conditions (FC)	I received adequate training when I began using HIE
	I have the resources necessary to use HIE
	I have the knowledge necessary to use HIE
	HIE is compatible with the other electronic health systems I use at work
	I can receive help when I have difficulties using HIE
	Viewing my patient's prescribed medications
	Viewing my patient's timeline of encounters

***TAM construct**

Appendix B- Interview Questions and Protocol

Table C Interview questions

Criteria	Interview question
Interaction	What could help you to interact with the system more frequently?
Clearness	What could help to make the information clearer?
Comprehension	What could be done to enhance visuals?
Ease of use	which information can be added?
Non-overloading	What does overload you and what do you suggest making the overloading less?
Non- distraction	What does distract you and what do you suggest making the distraction less?
Visualization	How could the 3D visualisation be enhanced?
Helpfulness	What do you still need to make better decisions?
Assistance	What do you still need to better find points of attention in the operation? Or how it can be improved?
Instructiveness	What could be added to the system that helps you to improve your skills?
Explicative	What could be added to help you see how other operators are working or how this feature could be enhanced?
Collaboration	What could be done/added to help you collaborate with other operators? or how this feature could be enhanced?
Effectiveness	What could be done/added to help you achieve higher-quality asphalt? or how this feature could be enhanced?
Performance Expectancy 1	What could be done/added to help you save more time and make your job easier?
Performance Expectancy 2	What could make you job easier?
Effort Expectancy 1	What could be done to make the learning process more efficient and make you skilful at using HCQ/SD shortly?
Effort Expectancy 2	What could help you to become skilful at using OSS?
Perceived Enjoyment	How these systems can be more enjoyable?
Social Influence 1	Do you suggest something that makes individuals in your workplace use HCQ/SD more frequently?
Social Influence 2	What should be done so that most individuals in your workplace use OSS?

Facilitating Conditions 1	What are the major points that should be included in the training?
Facilitating Conditions 2	What should the help consist of?
Use recommendation	What should be changed/enhanced in the system to become more recommendable for use?

Interview Protocol Form (University of Idaho, 2023)

Project: Assessing the use of Intelligent Compaction (IC) from the operator's perspective

Date ____________________________

Time ____________________________

Location _________________________

Interviewer _______________________

Interviewee _______________________

Notes to the interviewee:

- Thank you for your participation. I believe your input will be valuable to this research and in helping grow all our professional practice.
- I would like to audio-record our discussions today to make taking notes easier. If you agree, please sign ____.
- Confidentiality of responses is guaranteed.
- Approximate length of interview: 1 hour, three major sections.

Interview questions:

- As mentioned in Table C

Closure:

- Thank the interviewee.
- Reassure confidentiality.
- Ask permission to use his/her input in the research.

Appendix C- Thematic and SWOT Analysis

Table D Thematic Analysis

1. Data extracting + 2. Initial coding	**3. Themes + 4. Reviewing themes**	**5. Defining and naming themes**	**5.2 Main theme**
"It's strange that the system does not have a Dutch language option, if the manufacturer develops a system, it should be also available in Dutch." *"Systems should be in Dutch."* *"I don't speak Germany or English to give a system in these languages."*	System language.	Accessibility of the Language and User Attraction in IC Systems.	Interaction with IC system.
"Setting up a project in the Smart Doc system seems to be straightforward but requires a lot of work and cost time. This makes me feel bored." *"I turn on Trimble and it has project information automatically, So I don't need to fill anything."*	Setting up a project.	Setup Challenges and Efficiency in IC Systems.	
"I know how to create a project, but the whole top buttons on the screen, I have no idea what I can do with it."	System buttons.	Simplicity and Complexity of User Interfaces in IC Systems.	

"I only know the function of basic buttons on the screen." *"HCQ has many buttons."*			

Table E SWOT analysis

Strengths (Promote)	**Opportunities (Invest)**
• Clear information on the screen. • Information is easy to follow and nonoverloaded. • IC systems help more in big-scale projects. • Temperature measurements are more accurate in the new versions of rollers. • The support in case of a defect is sufficient.	• Some systems (SD) do not support Dutch. • Instillation of some systems (SD) is unsmooth and requires time. • lack of knowledge on what the buttons and options on the screen of systems further offer. • The temperature on the screen is preferred as a number. • A tablet is preferable to a big, fixed screen. • A fixed position of the OSS screen of some systems. • Screen lights at night work. • OSS is unable to register the offset rolling process. • Unable to register the places where roller operators have used the vibration. • The temperature measurement is not practical as they need to drive to that point to measure it. • Roller operators face difficulty in connecting rollers. They find the process complex for them.

	• Unable to communicate with the paver. • Not roller operators know all functions. • No adequate training has been given to roller operators before using the IC systems in daily work. • Roller operators are satisfied with the help they receive when they face a problem although it takes time till they get help. • Roller operators are not convinced yet about the benefits of using IC systems. • Roller operators indicated that they were not involved in the development or in the decision to choose a specific IC system.
Weaknesses (Solve)	**Threats (Control/limit)**
• Unable to detect colour, the texture of different asphalt mixes or soft spots and cannot share this information with other rollers. • Unable to detect areas that are under-compacted or over-compacted. • Inaccurate temperature measurements in old versions of the rollers. • Stiffness measurements are not accurate. • Lack of information that can help roller operators in decision-making. • IC systems are indicated as unenjoyable during use by roller operators.	• GPS signals in most systems can be interrupted and result in missed spots in the registration. • Safety concerns. • Multiple screens in the new generation of rollers. • Lack of communication between roller operators and management. • The function of connecting rollers is not always accurate. • IC systems are not promoted enough by individuals and the management to be used by roller operators.

	• Roller operators could be judged based on the results seen by management.