



# **Support for autonomously driven systems in harsh environments**

**Degree project for Master of Science in mechanical engineering  
with focus on innovation and sustainable product development**

**Mohammed Aljafari**

This thesis is submitted to the faculty of engineering at Blekinge Institute of Technology in partial fulfilment of the requirements for the degree of Master of science in mechanical engineering. The thesis is equivalent to 20 weeks of full-time studies.

The authors declare that they are the sole authors of this thesis and that they have not used any sources other than those listed in the bibliography and identified as references. They further declare that they have not submitted this thesis at any other institution to obtain a degree.

**Contact Information:**

Author:

Mohammed Aljafari

E-mail:

Mohammed195@live.se

University advisor:

Alessandro Bertoni

Mechanical engineering

Faculty of Mechanical engineering  
Blekinge Institute of Technology  
SE-371 79 Karlskrona, Sweden

Internet : [www.bth.se](http://www.bth.se)  
Phone : +46 455 38 50 00  
Fax : +46 455 38 50 57

# ABSTRACT

Symptoms of harsh environments create pressure on autonomous machines to work well with the use of measurement devices. Sensors used within construction equipment vehicles suffer from being covered with fogs of dirt, oil, water, and dust. Autonomous vehicle's dependency on fully functional sensors paves roads for research to be made on ways to keep sensor data from being compromised and automation to be improved.

In cooperation with Dynapac Compaction Equipment AB, this master's thesis problem opted for innovative and sustainable product development to tackle the problem. The thesis comprises of 30 credits. In this thesis, work will be done emphasizing on ways to keep autonomous performance at peak for construction equipment vehicles with low to no capacity for sophisticated equipment and supply of power and water. For reference, the project targets asphalt rollers due to their relevance at Dynapac.

With the use of innovative product development tools, the problem is to be tackled with an engineering approach revolving around the design thinking process. All progress will be constituted at Dynapac's facilities in Karlskrona. Interviews and dialogue with relevant individuals are to be held to create value based on customer needs which has been of high priority and is to be iteratively monitored throughout the project. Prototyping will play a part with large amount of testing to prove concept, including processes of 3d modeling and manufacturing of components.

With measurement incorrections reaching up to 80 degrees out of a measurement span within the range of 0 to 150 degrees, three concepts have been established, each of which are equipment neutral to benefit construction vehicles which has shown to be valuable within the industry.

Distancing sensor lenses from exposure to dust through air flow is an appropriate way to aid autonomous systems towards accurate measurements helping their behaviors. A pipe concept which's purpose is to hide the sensor further and create distance between sensor lens and measurement surface has been established. The concept is feasible for the construction industry, protects the sensor from debris and supports autonomous systems.

**Keywords:** Sensor, Temperature measurement, Maintenance free, Autonomous system

# SAMMANFATTNING

Symtom från tuffa miljöer skapar en utmaning för autonoma maskiner att prestera väl med hjälp av mätinstrument. Sensorer som används inom byggutrustning fordon lider i sin prestation på grund av dimmor av smuts, olja, vatten och damm. Autonoma fordons beroende av fullt fungerande sensorer öppnar vägar för ytterligare forskning kring metoder för att hålla sensordata från att försämrats parallellt med att autonoma system förbättras.

I samarbete med Dynapac Compaction Equipment AB, tar detta examensarbete sig an ett uppdrag inom innovativ och hållbar produktutveckling för att lösa problemet. Uppsatsen omfattar 30 högskolepoäng. I denna uppsats kommer arbete att göras med betoning på sätt att upprätthålla autonom prestanda för byggutrustningsfordon med låg till ingen kapacitet för sofistikerad utrustning och tillgång på elektricitet, vätskeförsörjning samt komplexa verktyg. Som referens riktar projektet in sig på asfaltsvältar tack vare dess relevans hos Dynapac.

Med användning av innovativa produktutvecklingsverktyg kommer problemet att hanteras med en ingenjörskraftig insats som kretsar kring design thinking-processen. All framgång har utformats i Dynapacs anläggningar i Karlskrona. Intervjuer och dialog med relevanta personer har gjorts för att skapa värde baserat på kundbehov vilket har varit av högsta prioritet och kommer att övervakas iterativt genom hela projektet. Prototyper har spelat en roll med mängd av tester för att validera concept där 3d-modellering och tillverkning för framtagning av komponenter inkluderats.

Med mätfel som når upp till 80 grader inom ett mätintervall på 0 till 150 grader har tre koncept etablerats, var och en av dem är utrustningsneutral för att gynna fordon inom byggindustrin vilket visat sig vara en merit just inom branchen.

Att dölja sensorlinser från damm och smuts är en lämplig väg att gå för framställning av noggranna mätvärden vilket också förbättrar systemens beteenden. Ett rörkoncept vars syfte är att förlänga avstånd mellan sensorlins och mätyta har slutligen framtagits. Konceptets är lättframtaget, skyddar sensorer från att bli smutsiga och stödjer autonoma system.

**Nyckelord:** Sensor, Temperaturmätning, Underhållsfri, Autonomt system, Design thinking

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# 1 INTRODUCTION

With the uprising of automation in the society where systems within vehicles and machines run without the monitoring nor management of humans, sensors and cameras take large responsibility for guiding these systems. This thesis problem is handed out in collaboration with Dynapac Compaction Equipment, a company that have provided an automated solution by the name Seismic for asphalt compactors to increase fuel efficiency and compaction quality[1]. Automation is controlled through measurements executed by sensors, sending data to the system to guide its operation. Sensors are to guide the behavior of the a system or machine and the level of accuracy determines the result of the operation[2]. Performance of systems relying on measurements of temperature from infrared sensors become compromised when sensors fail in reporting accurate values. Failures of measurement become reality when sensors are covered by dirt, liquids and gases that get stuck on the surface of sensors in question[3].

## 1.1 Problem definition

Machines that work within construction environments are constantly faced with filth and dirt covering the machines. Sensors that play a role within the function of the machine are affected by the pollution, where the lenses of the sensors get covered by pollution and debris causing the measurements of sensors to be compromised[2]. This stems from the measurement occurring on the dirt and not the intended surface. Autonomically driven functions, or in some cases fully autonomic vehicles, are therefore disrupted by such incident which makes the functions guided by the sensor act in an undesired way unless protected or cleaned[4]. A research question has been constituted to create a base for the project to build upon.

**Research question:** How may Infrared temperature sensors be protected by pollution in order to improve autonomous systems?

## 1.2 Purpose

This research aims to conclude ways for temperature measurement within the construction industry to be kept from becoming compromised by pollution. Acknowledgement of gaps in the markets that are to be filled by the project are to be made by creations of unique value propositions that will be applied and evaluated in the project.

## 1.3 Delimitations and risk management

The project is narrowed down due to context that otherwise creates a problem that is too general to be solved by a specific solution. Limitations are made to help direct the project and its methodology into value generating results according to the problem statement.

- Temperature measurement narrows the scope of the project, making research for solutions outside of this context irrelevant due to the requirements that are needed from a system in order to measure temperature properly.
- Sensors will be the measurement system of focus, mainly because of their frequent use within temperature measurement but also due to their availability for the project through the cooperation with Dynapac Compaction Equipment.
- Manually operated tools are not included within the research due to the focus being on automated systems. A manually operated temperature measurement solution would disrupt the autonomy in the systems and will therefore be disregarded.

Risks that may occur during the project are initially as following:

- Concepts achieved may not fully solve the problem at hand. Although they shall still provide information on ways that work better than the current system and ways that may not work at all.
- Some equipment may not be achievable to test and can therefore create a gap in the research. The concepts that include such equipment shall be evaluated with assumptions and discussed later in the report.

## 1.4 Background

Dynapac is a manufacturer of compaction equipment that are utilized within the construction industry involving compaction of soil, asphalt, and gravel. The company was founded in 1934 in Sweden, Stockholm and has since the year of 2017 been owned by a head company that goes by the name of Fayat Group. Approximately 1300 employees around the world are claimed to work in the company. Departments are located in several places around the world with Karlskrona being the headquarter and location of development and production of roller compactors[5].

The effect that dirt has on measurement data made by infrared temperature sensors is deemed critical, making difficulties for a system to behave correctly due to incorrect measurement. This is in fact one of the downsides with infrared sensors[6]. Dynapac Compaction Equipment AB is an example of a company that suffers from the consequence of polluted temperature sensors. Autonomous running of systems is to be compromised and their purpose downsized. Construction machines with autonomous systems show promising results for efficient use of energy and time and can allow for cheaper construction cost due to the latter. Asphalt roller compactors, that are part of the construction industry profit by margins from such solution [1]. Sensor data is therefore crucial, allowing for a sophisticated execution of measurement to support an autonomous system like the one mentioned above.

To perform measurement on a current basis, sensors are mounted on the front and back of the machines. Measuring the temperature of the asphalt before the drums drive over to compact it is crucial and lead the company to mounting them with a reading direction on the asphalt in front of the drums. The drums pour water to cool down and to prevent the asphalt from sticking onto them. Sensors therefore become vulnerable due to their location just above the drums, (see figure 1 below).



*Figure 1: Asphalt roller compactor with sensor mount in the middle, above the drum.*

Sensors on construction equipment that operate outside, in harsh environments such as asphalt compaction have not only dust and nature's pollution to deal with but also the smoke and condensation coming from asphalt when it's freshly laid. Pollution is then led from the condensation of smoke particles created when the asphalt is laid[7]. Sensors are then prone to be reached by potential dirt that cover them further (see figure 2 below).



*Figure 2: Asphalt compaction machine in a construction environment creating a large amount of pollution.*

## 2 RELATED WORK

There are ways that have been explored previously to maintain sensor and camera lenses with the purpose of keeping accurate measurements and capturing of data collected by sensors and cameras.

### **Cleaning system – Fluid spraying nozzles to clean lens surfaces.**

Within a thesis paper made on sensor cleaning systems for autonomous vehicles, former students from KTH have worked on a system to aid autonomous vehicles. The system has been formed to solve a problem with many vehicles using sensors, lidars and cameras. Its purpose is to maintain sensors and cameras and to prevent compromise in measurement which according to the thesis is particularly important with the upbringing of fully autonomous vehicles where safety aspects are crucial. The work done covers nozzle pressures and patterns in which the liquids sprayed has an impact on the cleaning itself. It provides a form of solution to sensor maintenance in the shape of preventing environmental pollution to interfere with the performance of the sensors that result in lesser performance by the system that is guided by sensor data. Using spray nozzles and adapting their beam strength and pattern helps alter the strength of which the lens surface is impacted by when reached by the fluid from the nozzle.

The work presented here has functional potential for a wide range of context but lacks when it comes to harsher environments where materials can stick to the surfaces due to oil and sticky characteristics that are common within construction industries which makes this solution falter in its performance. In addition, vehicles with limit to equipment capability, such as power supply and room for supply in water and liquids, this solution falls due to its dependency on power and a supply of water and fluids that can remove sticky particles[4].

### **Stream Data Cleaning for Dynamic Line Rating Application**

An effort into data management of errors from weather reading sensors has in this report been researched in order to counteract faulty recordings from sensors due to harsh environments. This work focuses on replacement of faulty data with regard to historical recordings. It helps the system work around the problem but the replaced data comes with margins of errors [8].

This kind of approach is relevant considering that the sensor's purposes are to achieve data and guide an autonomous system to desired behavior. Such system finds lacking within the area of this project due to the unpredictable changes of temperature. One example can be the transition from cold asphalt to warm asphalt for a compaction roller. The change is not predictable and therefore disqualifies such approach to the problem at hand in this project.

Works presented offer solution-based research regarding reading errors in sensor measurement. There are yet gaps to be filled within the research due to the difference in context coming from what industry and how the sensors are expected to be used. It goes hand in hand with the delimitations of the project.

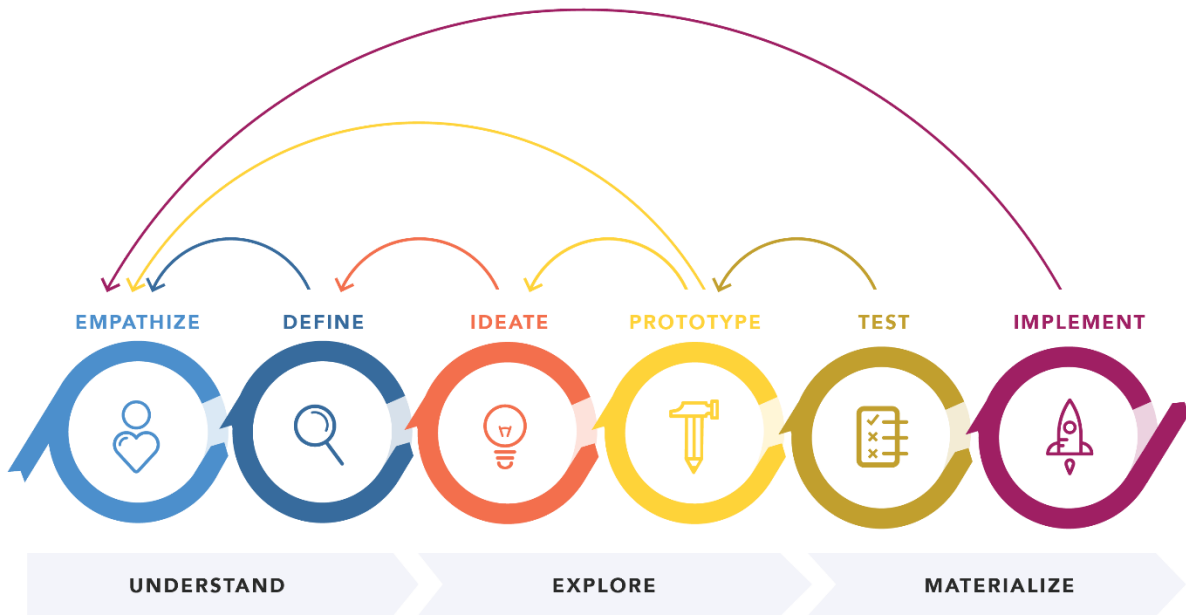
### **3 METHOD**

In order to answer the stated research question in this report, certain methods have been used. Methods chosen are to develop a product with focus on customer needs to conduct a value generating product. Fundamentally, the main product development method is design thinking. The problem at hand is complex and can be solved with a variety of approaches. Asphalt rollers, that are the main target of this thesis operate in harsh environments, making the understanding of this specific problem crucial. Design thinking is an ideal approach when it comes to an innovative user-oriented product development and design thanks to its weight on iterative communication with and understanding of customers in order to achieve an ideal product[9]. Design thinking follows with methods connected to it that are used in this project and are to be described in this section.

#### **3.1 Design thinking**

A product development tool has been used in this project to achieve the best possible outcome, having user needs and pains in focus. Design thinking is the specific tool of use to iteratively work in phases that all come down to satisfying the customer. Stages that have taken place within the approach are five and are initiated by the emphasize phase. Here, an understanding of what the problem is and why the problem is formulated in the first place has been examined. This stage is therefore surrounded by events such as interviews, observations and identifications of users that have interest in potential solutions along with people that don't to find out ways to attract them. Next phase is define. It consists of conclusions regarding the problem and what the findings are. Halfway through the design thinking process, ideation takes place and brings forward brainstorming with regards to the findings and conclusions that are were constituted. Ideas were then generated with the aim of quantity. Moving on, prototyping is the next objective, where ideas generated are supposed to be brought to reality through small scale solutions that display the functions of selected concepts brought from the brainstorming phase. The idea behind this is to get a rough estimation of the functionality and investigate whether or not the concept is successful. It is merely a version of the ending product are therefore created with low fidelity. Finally comes testing although this is not considered to be the end of the road. This phase is about trying out the solutions and to put them against each other in evaluation. Design thinking is taken advantage of to structure a product development process in a value generating manner that focuses on user needs at all times[10].

The key with design thinking is the that the process shall be iterative. Stages can cause need of redefinition and identification of new problems that need solving[11]. Working across the different stages is therefore to be done in the project to optimize the value of the product by constantly attempting to satisfy customer needs (see figure 3 below).



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Figure 3 :Design thinking methodology, adapted from [12].

The double diamond is another strategy intended to be used which is linked to Design thinking and is a strategic approach from an engineering perspective. It helps structure the project and keep it organized although still iterative (see figure 4 below).

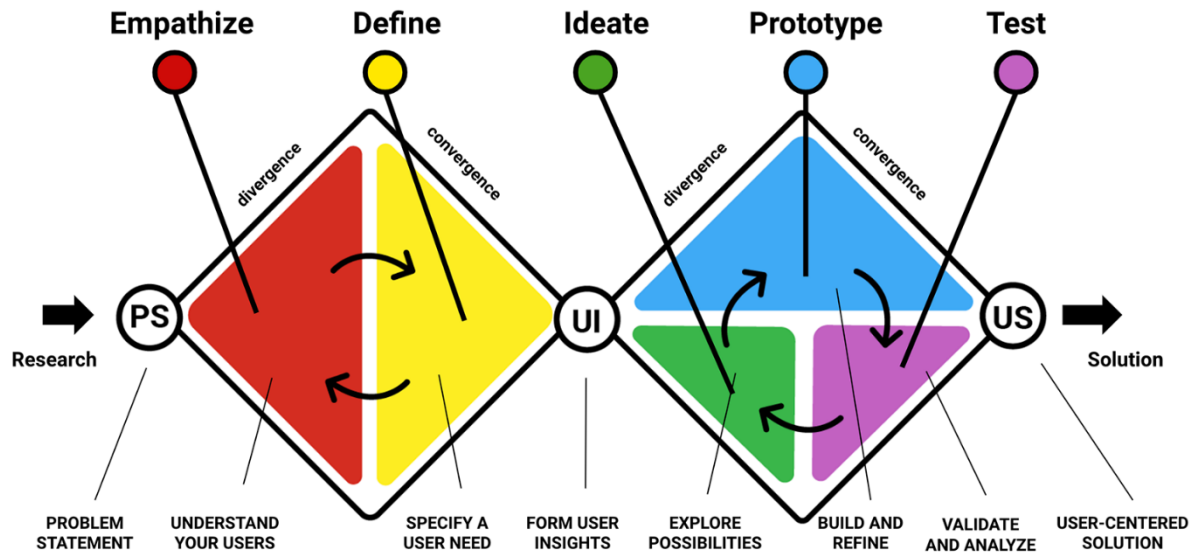


Figure 4: Double diamond strategy, adapted [13].

The double diamond is initiated by a diversion, where answers and information are searched for to collect a well-rounded view of the user needs and requirements. Continuing from this stage, it was then time to make conclusions of what is achieved. Here, statements of the needs from the user were assigned, helping to direct the project towards a user-focused product development process. Using the information gathered in previous phases, ideas of relevance yet with no limit in technical aspects have been generated. All possibilities have been welcomed which formed the divergence of the project with the help of brainstorming directed towards quantitative results. Ideas haven then become converged and brought down to concepts and evaluated against each other with respect to criteria that are convenient for the project and the customer. Testing is a very important stage and is to validate the functions of the concepts which are included within the convergence stage of the project. Iterations have occurred throughout the whole process to add customer value to the product before a solution is chosen and built upon[13].

This tool was used to structure the research on how to protect temperature measuring systems from pollution by with constant focus on the customer. The structure allowed for sophisticated research encouraging value generation for the product to answer user needs which creates a product that is based on filling gaps in the market.

## 3.2 Testing

Tests were made at Dynapac's production and service facilities with tools available at the company. This included all the work revolving around measurement and identification of current sensor context. Several testing sessions are made to gain further information about the context of



the problem. Roller compactor machines available at Dynapac have been used in different experiments along with tools for measurement.

### **3.3 Data collection**

Design thinking includes understanding of the problem, pain points with the current product but also the wants and needs from customers. Dynapac being the reference point of this project became a focus regarding collection of information about the problem. Several tours around existing machines with relevance were held for observation where the sensors are investigated and the cause of the problem evaluated. Apart from observing the sensors, discussions were being held with people at Dynapac with relevance to the project. This includes dialogues with four engineers and interviews with two service managers and one mechanic. Interviews took place in the early stages of the project where the maintenance and pain points of the existing system were emphasized on. Data from each process was immediately extracted and documented.

Data was also be extracted through outsourcing during the ideation phase. Small interviews were held at and outside of Dynapac including people of different backgrounds. People interviewed were both relevant and irrelevant to cover thoughts and opinions with different of different perspective. Outsourcing has been constituted to ensure quantitative brainstorming and to have access to as many ideas as possible.

### **3.4 Stakeholder analysis**

Identification of influential people and corporations is made in the project to form features of a final product based on important targets. These targets have interest and power in different levels and have been mapped to emphasize on aspects regarding the product that will be more crucial to implement to generate more value. Two tools are taken advantage of to map out stakeholders of relevance to the project.

One of the tools is the stakeholder salience map. This tool describes how crucial each of the stakeholders are for the project to be successful is here acknowledged with placements according to how much power, interest and need of change a stakeholder has [14].

The second approach is a power-interest grid that categorizes the stakeholders within power and interest. Each stakeholder is placed depending on how much power and influence they have along with how interesting a potential change is to them[15].

These tools are used to identify what stakeholders to focus on when approaching different steps in the project. It helps extraction of data by making interviews with the right people and to determine what features are important to contemplate in a potential final product thanks to identification of stakeholders.

### **3.5 Tech and trend watching**

Observations of existing solutions regarding accuracy of measurement to keep autonomous function have been performed. Sensors with relevance to the project have been reviewed, both on function to identify potential in other kinds of sensors but also on gadgets that can keep the performance of the sensor consistent. Sensors are not the only kind of tool to measure temperature, other solutions for temperature measurement will be brought to light having other features of interest to the solution. The look for existing solutions also steps outside of the construction sector

all the way to the vehicle and security industry with the purpose of scavenging the market to detect what kind of technology that exists.

Online dialogues through email with companies of relevance or potential suppliers have been constituted within the tech and trend watching to collect data on the different features and solutions that exist on the market. This has ensured a complete and accurate extraction of information on products and has aided the ideation process.

Another approach was a competition overview. Other companies within asphalt compaction have been viewed in terms of sensor placement and gadgets used for the sensor. This was to gain knowledge on potential solutions but also to identify gaps to cover on the market. Each system used within the companies was overlooked for further background regarding the sensor use and revolving applications.

### 3.6 Business model canvas

For a solution become relevant, it is crucial for it to have potential of generating income. This can be measured by how well it compares on the market and how the solution can be put forward as reasonable for implementation. With the help of a business model canvas, aspects revolving around the business model has been addressed to pinpoint the strength of the solution,

Below, in figure 5 , a business model canvas [16] is shown and illustrates the different aspects that are taken into consideration in terms of the business model that the solution will follow.

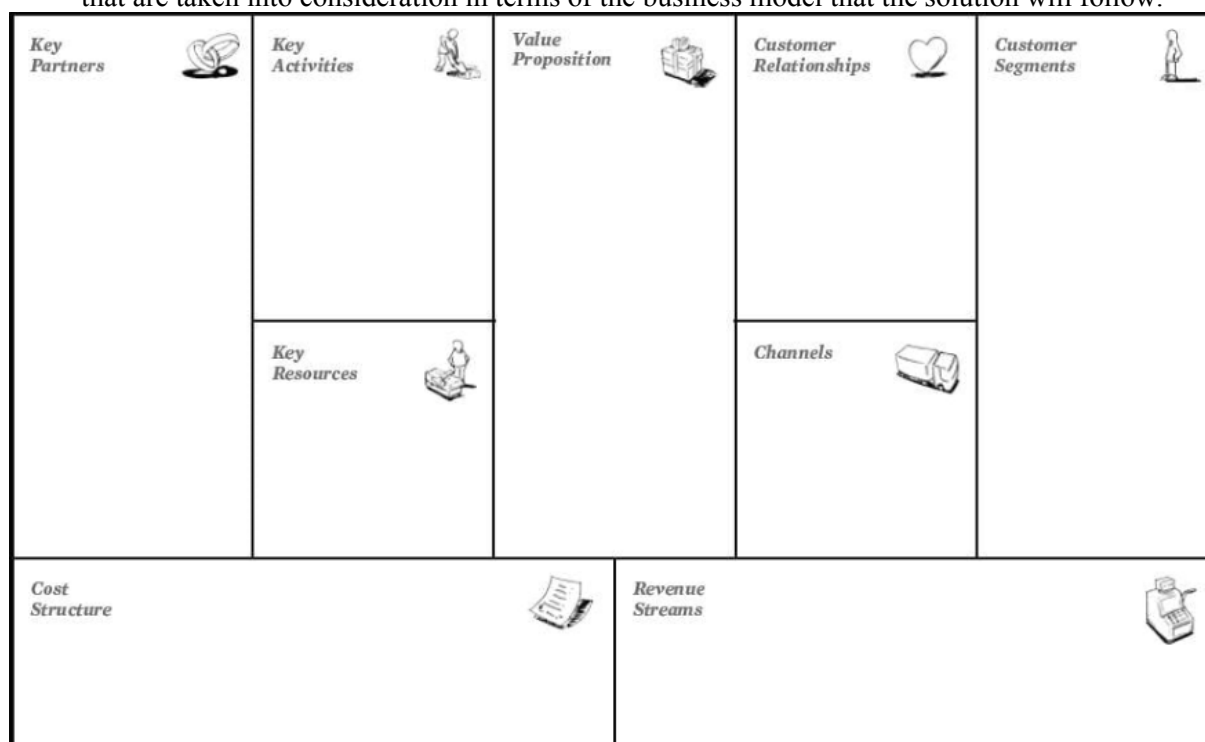


Figure 5: Business model canvas , adapted from [16]

The business model canvas (BMC) consists of 9 paragraphs including information about the product from a profit perspective.

#### 1. Value propositions

Creating a picture of what is gained in terms of advantages by the product is to be made in this paragraph. It states what value the customer is getting from buying the product.

## 2. Customer segments

This stage of the BMC addresses the persona of the customers and who the target of the product is. Empathizing with the personality of the user is important to create a value generating product, these traits will be presented here.

## 3. Customer relationships

Optimizing relationships with the customer and potential customers has importance and the methodology is mentioned here. Interactions that create a strong bond will here be stated.

## 4. Channels

This part describes the way of reach for the value propositions. How the value will be delivered and arguments supporting the value also have their home here.

## 5. Revenue streams

A mapping of ways to create revenue is made here, with all kinds of maintenance, service and product selling revenues taken into account. This part describes the value for the company itself and in what way profit can be acquired if this product goes on the market.

## 6. Key activities

Activities performed to push the proposed value weigh their part and also have a place in the BMC. Activities can be done within production, delivery and also function of the product that help the customers solve the problem they have at hand.

## 7. Key resources

Resources crucial for the product to be successful are to be mapped and evaluated. Such can be finances, materials and influence that create product value.

## 8. Key partnerships

Business partners have a large impact on the value of the product. Everything from suppliers to advertisement managers should be emphasized on in this area.

## 9. Cost structure

Since it's a business model regarding profit and revenue, expenses play a big role in the success of the product. A review of different costs with differences in levels of expense are to be evaluated in this section.

# 3.7 Prototyping

Construction of several prototypes has been made within the project to validate concepts and ideas. Concepts are fundamentally created in a simpler version to test the performance a potential final product. Each concept has been prototyped to validate whether it is a valid approach towards improved automation to answer the thesis' research question. The prototypes are then to identify whether the concepts do allow for a maintained sensor which further helps automated systems to function accurately.

All prototypes were created with tools and equipment in Dynapac's facilities. Sketching and idea visualizations have been established and handed to a prototyping workshop where the prototypes are quickly built. This allowed for a faster prototyping phase and for more prototypes to be built.

To test the concepts that have been achieved throughout the process, a day was dedicated to running an asphalt compactor. Asserted concepts were during the time put into a harsh environment to validate their capacity of support for autonomic systems. Comparisons of measurement accuracy were then executed to validate each concept and evaluate its functionality. The test was aimed to be environmentally friendly and cost effective which was achieved by testing all concepts at once using mounts that were be designed and manufactured at Dynapac. The concepts in question were put into test with environmental context being as close to conceptual context as possible. Sand, gravel, and water were used as a dusty environment on a testing track at Dynapac challenging all the concepts along with an original sensor. An original sensor with previous context has then been used to keep a reference for comparison to identify potential improvements that the concepts achieve.

### 3.8 Concept selection

Approaching the choice of concept, it is beneficial to outsource and it is to be done with several personalities with relevance in the matter. Engineers at the product development department within Dynapac are have had influence in the concept selection through criterion development. Along with prototyping and validation, the criteria's influence then determines the concept selection based on the use of Pugh's matrix.

#### 3.8.1 Pugh's Matrix

Pugh's matrix is a concept selection tool used to rank concepts against each other based on criteria. Importance of criteria determine how much a certain criterion weighs and then amplifies the ranking of a concept based on its severity. Standards for each criterion are to be set creating a reference point for the concepts to follow. Concepts were then evaluated and identified to either match, exceed or be inferior to the set standards. Signs were then set to indicate each criteria's results in the shape of a 0 for matching standards, a + for concepts exceeding the standards and a – for concepts underperforming in comparison to the standards[17] (see figure 6 below).

		Alternatives				
Criteria	Baseline	Concept 1	Concept 2	Concept 3		
Safe	0	–	–	0		
Durable	0	+	0	–		
Weight	0	–	–	+		
Easy to assemble	0	+	0	–		
Reliable	0	–	–	–		
Cost	0	+	0	+		
	0					
	0					
	0					
Totals		0	-3	-1		
Rank		1	3	2		

Figure 6: An example of a Pugh's matrix with 3 comparing concepts[18].

Pugh's matrix was used to establish a concept selection based on user needs and requirements to amplify the value of the product and create attraction to it. A final concept was then chosen based on its performance during tests but also how well it handles each criterion which will give it a ranking as shown in figure 6 above.

### **3.9 Designing and sketching**

Sketches and drawings have been created to illustrate ideas and prototypes for building in workshops. Simple sketches for brief presentations of ideas were constituted using Paint and Powerpoint presentations. Presentations of ideas was then made at Dynapac with three engineers to keep an iterative feedback-based process that pursues customer needs. On the other hand, designs were created through CAD programs, both CREO and Autodesk inventor. Some of these designs have then been applied into 3d-printing while others in the shape of drawings have been used to display instructions for prototype building at the prototype department at Dynapac.

## 4 RESULTS

### 4.1 Identified demand

Product expectations are achieved through needfinding and are strictly focused on value generation for the customer. Dynapac Compaction Equipment has been the basis for customer needs. Interviews have taken place with people within Dynapac working at service, construction and manufacturing.

Interviews involving engineers, service managers and a mechanic were constructed at Dynapac. The company aims to implement a new system that regulates vibration frequencies of the asphalt compaction drums allowing for the drums to vibrate according to the asphalt temperature. Current systems do not regulate the drum frequency automatically. Operating frequencies stay the same unless regulated by driver and are adequate to execute the work but cause waste of fuel and energy. This is due to frequencies being higher than what is needed when temperatures of the asphalt decrease. The drums are then not in need of higher frequencies for the asphalt to be compacted properly which leads to unnecessary power and fuel consumption. Apart from waste, drums are then exposed to unnecessary wear. Sensors that are mounted show values of the asphalt temperature but are known to become incorrect when polluted which occurs during a day of work. Machine users tend not to maintain the sensors by cleaning which leads to the sensor becoming irrelevant.

Observations around the machines themselves shows deficiency in capacity for equipment and power. Additionally, dialogues with engineers at Dynapac have emphasized how restricted the machine is regarding the mentioned aspects.

Further pain points were taken through dialogues with the service department at Dynapac where a service manager was interviewed about the use of the machine regarding the temperature measurement. Input is presented in table 1:

*Table 1: Information gathered about the problem from an interview with a service manager at Dynapac*

1. Temperature measurement is currently used to determine when to stop compaction.
2. Rough environment creates layers of fog from steam,oil, water, detergent (from drums) and diesel.
3. The sensors are prone to being cover by layers of dirt.
4. Cleaning requires detergent against sticky liquids such as oil and diesel that are also combined with dust. These contain dissolvents and alcohol. Cleaning is therefore not enough when only done with a brush.
5. Machine operator ignores maintaining the sensors by cleaning – they are left compromised by the pollution.
6. Sensors are replaced after a certain amount of time due to damage.
7. The system has previously consisted of a sensor being mounted at the middle of the machine, It did not fault the function of the sensors. Sensors were then better at performing despite pollution.
8. Temperature is sometimes measured with manual thermometers. The sensor is at that point too blurred by pollution.
9. Temperature faults range between 0 and 80 degrees.

These are factors preventing an autonomous operating of the drums. In some cases, the debris caused during compaction is severe enough to require sensor changes which is expensive keeping the service in mind.

Requirements and user needs have been established through interviews with three engineers at Dynapac, they are translated into criteria and will be used in the ranking of different concepts further on in the report. Criteria and requirements have been stated along with their importance within the product (see table 2 below). All criteria are based on customer needs but some come with more weight than others. To distinguish between their importance and emphasize on the prioritized aspects of concepts, each criterion is marked with a percentage dictating its weight on in the final product.

Table 2: Criteria and requirements with percentual ranking according to importance.

<b>CUSTOMER REQUIREMENT AND CRITERIA</b>	<b>IMPORTANCE (0-100%)</b>
<b>Minimal maintenance</b>	<b>20%</b>
<b>Feasible (easy to implement)</b>	<b>10%</b>
<b>Precision of measurement</b>	<b>10%</b>
<b>Oil, water and dust resistant</b>	<b>5%</b>
<b>Low cost</b>	<b>10%</b>
<b>Voltage of maximum 24 V</b>	<b>10%</b>
<b>Functionality</b>	<b>5%</b>
<b>Size</b>	<b>10%</b>
<b>Less need of equipment</b>	<b>10%</b>
<b>Material waste</b>	<b>5%</b>
<b>Easy to construct</b>	<b>5%</b>
<b>Total percentage</b>	<b>100%</b>

It is obvious that maintenance, feasibility, accuracy, cost and a restricted need of equipment is concluded to be the most important features of a potential product.

## 4.2 Stakeholder analysis

Stakeholders can have a crucial effect on the success of the project, mapping them out to prioritize depending on importance is therefore beneficial and can create more value for the product considering what needs there are to satisfy. To create a visualization of the importance of each stakeholder, a stakeholder salience map is constructed (see figure 7).

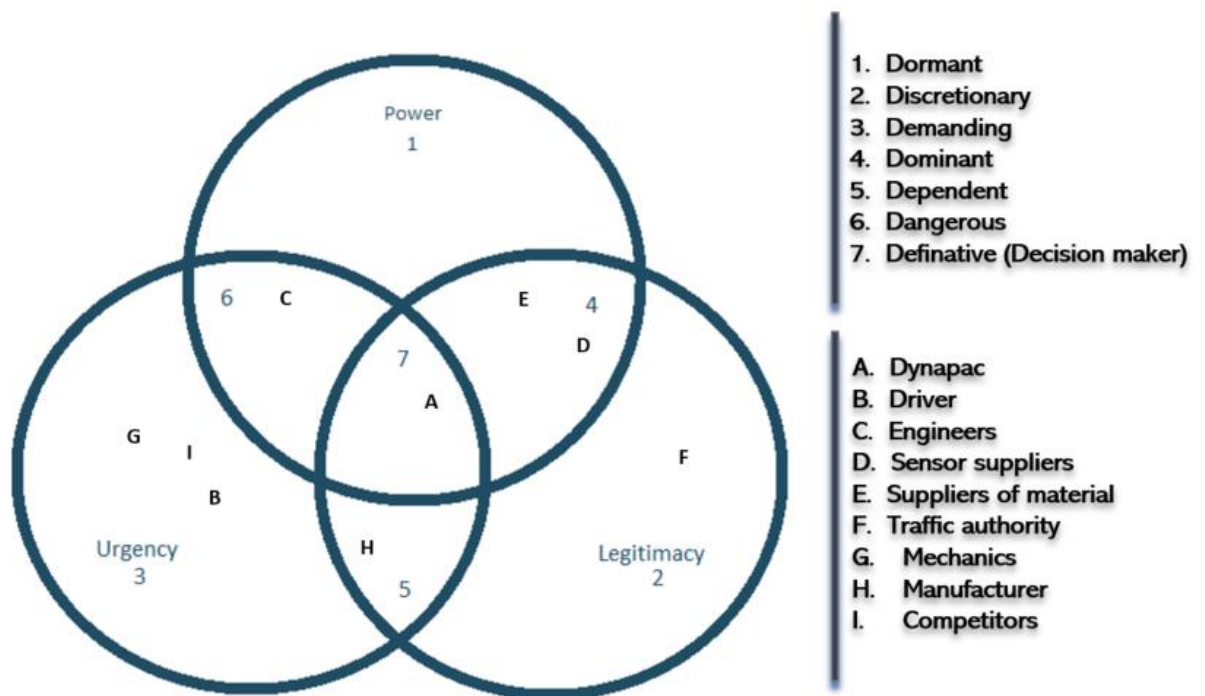


Figure 7: Stakeholder salience map.

Stakeholders that are considered have an impact on the project, some directly and some from further away. The classes used for this stakeholder map are described by the following:

1. Dormant – Has power but not the intention to impose change.
2. Discretionary – Can gain advantage from corporate decisions.
3. Demanding – Has claims, but no power to implement.
4. Dominant – Has a direct connection with the organization or project.
5. Dependent – Are dependent on others to get what they want.
6. Dangerous – Have powerful claims that could be dangerous for the project.
7. Definative – High salience and mostly important to the project.

It is important to mention that the ones that are in most interest to the projects are falling into the categories 7,6,5 and 4. Category 7 is the most important, making huge impact on the success of the project and should therefore be monitored closely. Dynapac is therefore the stakeholder in priority due to them being a crucial part of the research but also because of their interest in and need of a potential solution to the problem at hand.

Further, a breakdown of categories in which the stakeholders will be mapped out in a power interest grid to emphasize on their importance is created and visualized in figure 8 below.



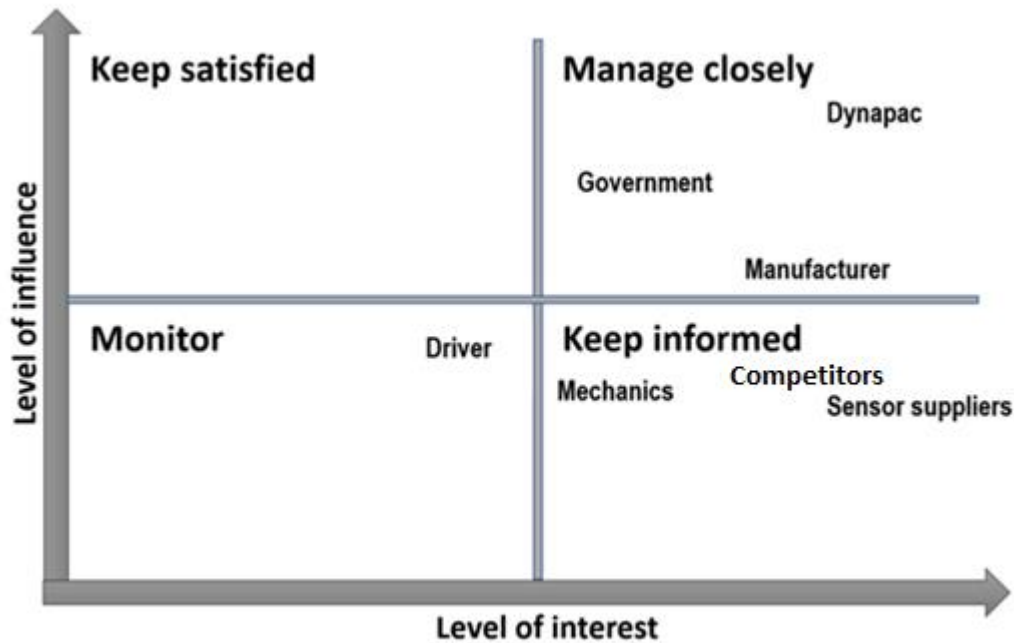


Figure 8 :Stakeholder power-interest grid mapping.

Dynapac stands for a large amount of power and have a big influence on the success of the product. This is due to the input they have regarding money and access to tools and equipment that generate value in the product. Simultaneously, Dynapac are the problem owners of the project and therefore have a large interest in the outcome. They are therefore going to be considered carefully throughout the process.

Governments that are responsible for the areas in which the product will function have an impact on the success as well. The product has to be approved from a legal point of view, potential legislation applies pressure on the product which makes the government an important stakeholder to keep at watch. Interest in the solution exists through the importance of lower emission and a well paved asphalt. It categorizes the government as an important stakeholder and therefore needs to be managed closely.

Manufacturers and mechanics are very similar in terms of their importance for the project. An assembly of a roller machine with a temperature measurement system occurring in the manufacturing phase involves the input of manufacturers. Their ability and encouragement to install the product makes them important considering that their level of input affects the result of the product. Manufacturers want a simple implementation, and the product is therefore of certain interest to them. Mechanics have slightly less influence but should yet be monitored closely due to the maintenance of the product. Interest stems from how manageable the process of maintenance is for them.

Driver's interest lay in the result of the product. The faults of the current system causing need of frequent maintenance in the shape of cleaning conducts interest in a system that is free of maintenance. Influence stems from how they use the product. User behaviour can limit, alternatively thrive the success of a product which concludes a relatively high influence from the user in this project.

Interest is very clear within the supplier sector as they benefit from potential solution. It increases their ambition in delivering qualitative components, but it also generates them a significant amount of influence as they influence the product with their products. Poorly performing supplier products will undoubtedly compromise the performance of a solution created within the project and it therefore increases the importance of suppliers.

The power interest grid along with the stakeholder salience map concludes important people and corporations that are crucial to monitor for the project to be successful. Those of interest will be kept in mind and addressed throughout the project to create value and bring satisfaction out of the potential product.

## 4.3 Tech and trend watching

An overview of existing market options has been made to identify further gaps that can be filled by a potential solution. Research made in the market has targeted sensors and features that can aid with its approach to the project research.

### 4.3.1 Sensors

A wide range of sensors have been viewed with focus on their ability to function persistently despite their surrounding environment of harsh nature. Sensors within the industry have been searched for (see table 3 below).

*Table 3: Market overview of sensors.*

NAME OF SENSOR	PROS	CONS	REFERENCE
Thermalert TX	<ul style="list-style-type: none"> <li>• Additional air purge feature can be used.</li> <li>• Cost neutral</li> <li>• relevant measurement ability</li> <li>• Lens protection, a “protective window”</li> </ul>	<ul style="list-style-type: none"> <li>• Large amount of unused measurement performance</li> </ul>	[19]
CM Raytec	<ul style="list-style-type: none"> <li>• Additional air purge feature can be used.</li> <li>• Cost neutral</li> <li>• Relevant measurement ability</li> <li>• Lens protection, a “protective window”</li> </ul>		[20]
CI Raytec	<ul style="list-style-type: none"> <li>• Additional air purge feature can be used.</li> <li>• Cost neutral</li> <li>• Lens protection, a “protective window”</li> </ul>		[20]
Thermalert 4.0	<ul style="list-style-type: none"> <li>• Lens protection, a “protective window”</li> <li>• Additional air purge feature can be used.</li> </ul>	<ul style="list-style-type: none"> <li>• Large amount of unused measurement performance</li> </ul>	[21]
Thermometer TIM 8	<ul style="list-style-type: none"> <li>• Robust</li> <li>• Adequate reading range</li> </ul>	<ul style="list-style-type: none"> <li>• No protection of lens</li> </ul>	[22]

Icron Modline 4	<ul style="list-style-type: none"> <li>• Robust and heavy.</li> <li>• Created for harsh environments.</li> <li>• Additional air purge feature can be used.</li> <li>• Adequate reading range</li> </ul>	<ul style="list-style-type: none"> <li>• Air used has to be industrial.</li> <li>• Expensive</li> </ul>	[23]
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There's a common theme seen among the sensors found which is the addition of an air purge feature. This feature provides a layer of air provided through a compressor that keeps the air away from the lens. Along with this feature, a protective layer of silicone (protective window) may be applied to help the lens from being polluted or damaged. Interactions with manufacturers of each product concluded need of further maintenance despite addition of features as stated in the table above. Protective windows need replacement after approximately a month of use, indicating yet reach of pollution despite the protection of an air purge.

#### 4.3.2 Features on products that improve accuracy of measurement.

After a search for possible solutions on the market, it is evident that the use of automatic spray nozzles to clean the surface of sensor and camera lenses is a common approach for autonomously driven systems which has been reviewed in related works earlier in this report. These come with water distribution followed by air that is sprayed to either cameras or sensors to clean lens surfaces and improve measurement and image capturing accuracy.

Further on, for sensors in specific, it is common that maintenance in the shape of air purging is used to protect the lens from pollution [24]. Maintenance is to be achieved by constantly providing air around the lens to push away dust, dirt and liquids from reaching the lens. Air is provided by a compressor.

#### 4.3.3 Competition overview

Bomag and Volvo Construction Equipment (Volvo CE) are competitors to Dynapac with individual takes on the sensor context and use. They are all manufacturers of asphalt compactors that work within harsh environments which make them a perfect review target for this project.

Bomag have their sensor placement underneath the machine between the drums. The sensor is used to determine temperatures in the asphalt and instruct the driver on how to operate the machine in order for it to be efficient and compact the asphalt with high quality[25].

Volvo CE has a similar sensor location to the current one on Dynapac's machines. Sensors are placed above the drums. In the case of Volvo CE, the sensors are used to create a digital driving track for the drivers to follow, helping them locate areas that need further compaction and avoid finished ones[26].

Apart from use, both companies show no differences to Dynapac in terms of sensor equipment. Volvo CE displays a similar context to Dynapac while Bomag's sensor placement distinguishes it from the two companies. It creates further interest to the application and makes sensor placement an interesting aspect to research further on in the project.

## 4.4 Brainstorming

In this section, the ideation phase of the project is presented. Ideas were generated with no limit nor respect to feasibility. Brainstorming took place at Dynapac and outside of the company for outsourcing, involving people of both relevant and irrelevant background. Initially, 2 engineers with mechanical background participated in the brainstorming at Dynapac. Worthy of mentioning is that these engineers

had no previous ties to the project. Discussions were then held with 3 mechanical engineering students at Blekinge Tekniska Högskola university to support the brainstorming. Finally, 5 individuals with no educational relevance within the area were introduced to the topic and contributed input to the brainstorming. Sketches on a basic level were made to enhance understanding within the project but also to present idea proposals at Dynapac. Generated ideas have not been limited by any boundary to increase the creativity of the process. 18 ideas have been constituted. To briefly describe each idea, an exposure of its pros and cons have been listed and evaluated (see table 4 below).

*Table 4: Ideas generated during the ideation phase. See appendix 1 for figures according to numbers stated.*

Ideas	Description	Pros	Cons	Figure number
<b>Replacement- Between drums/beneath machine</b>	Placement of sensor between drums , hidden in a space where pollution cannot reach	<ol style="list-style-type: none"> <li>1. Less pollution on lens</li> <li>2. Distance to asphalt can be shorter depending on placement</li> <li>3. Easy to install</li> <li>4. Simple system</li> <li>5. Less need of maintenance</li> <li>6. Low cost</li> </ol>	<ol style="list-style-type: none"> <li>1. Measurement after drums pass asphalt-less accuracy in measurement</li> </ol>	24
<b>Replacement- On top of machine</b>	Sensor mounted on top of cabin	<ol style="list-style-type: none"> <li>1. Less pollution on lens</li> <li>2. Easy to install</li> <li>3. Feasible</li> <li>4. Less need of maintenance</li> <li>5. Low cost</li> </ol>	<ol style="list-style-type: none"> <li>1. Far away from asphalt</li> <li>2. Harder to maintain in case of need.</li> </ol>	25
<b>Temperature stick instead of sensor</b>	A stick instead of infrared sensor. In contact with asphalt for measurement.	<ol style="list-style-type: none"> <li>1. Low cost</li> <li>2. Pollution does not affect accuracy.</li> <li>3. Pollution doesn't affect it</li> <li>4. Doesn't need maintenance</li> </ol>	<ol style="list-style-type: none"> <li>1. Has to be in contact with asphalt</li> <li>2. Can easily break</li> <li>3. Leaves marks behind</li> </ol>	26
<b>Air purge</b>	Air flow continuously blowing in front of sensor to avoid pollution from reaching	<ol style="list-style-type: none"> <li>1. Decreases need of maintenance</li> </ol>	<ol style="list-style-type: none"> <li>1. Requires compressor and pump.</li> <li>2. Needs more power</li> <li>3. Takes away space</li> </ol>	NA
<b>Vacuum</b>	A ring of vacuuming circling the sensor lens, sucking pollution before it reaches the lens.	<ol style="list-style-type: none"> <li>1. Power supply strong enough creates large potential</li> </ol>	<ol style="list-style-type: none"> <li>1. Requires a numerous amount of equipment</li> <li>2. Requires more supply of power</li> <li>3. Expensive</li> </ol>	27

Ideas	Description	Pros	Cons	Figure number
<b>Liquid and air blowing system</b>	Pumps washing away pollution with soap followed by a blow of air to dry the lens.	1. Fully automatic	1. Requires extensive equipment 2. Requires more supply of power 3. A big size solution 4. Expensive	28
<b>Hide lens further up/cover it more</b>	Create a deeper housing for the sensor lens to sit further inside.	1. Low cost 2. Creates further distance for pollution to travel in order to reach lens 3. Less maintenance 4. Easy to implement	1. May still be reached by pollution	NA
<b>Pollution-magnetic cloth</b>	A cloth surrounding the lens to drag pollution of all kinds towards it and keep the lens clean	1. High potential to work 2. Easy to install 3. Low cost	1. Hard to implement 2. Difficult to keep away liquids and dirt at the same time	29
<b>Vibrating sensor lens</b>	Sensor lens vibrates with frequencies making patterns for the pollution on it to follow. The pollution is then pulled away from the lens	1. High potential to work	1. High cost 2. Difficult to implement 3. Requires multiple additions of equipment	NA
<b>Nano-spray</b>	Coating that makes the lens of the sensor reflect the pollution	1. Low cost 2. High potential 3. No need of equipment 4. Long durability	1. May still need maintenance in the shape of cleaning 2. Reapplication shall be made as part of service	NA
<b>Protective window</b>	An additional lens out of silicone that performs well against dust	1. Keeps sensor lens from being scratched 2. Low cost	1. Not reliable for temperature readings if implemented alone 2. Needs to be replaced regularly	30
<b>Pollution-absorbing lens</b>	Sensor lens that absorbs the dust to clean its surface.	1. Big potential theoretically 2. No need of maintenance	1. Difficult to implement 2. Need of new very advanced and redesigned sensor 3. Need of equipment 4. High cost	NA

Ideas	Description	Pros	Cons	Figure number
<b>Sensor placement inside drum</b>	By making a rinse in the drums, the sensor can be place inside and measure the temperature through the hole	1. Very good protection for the sensor	1. Creates weakness in drum strength 2. Requires complete redesign of machine 3. Very difficult to implement	
<b>Mirror angling</b>	By providing a mirror, it reflects the ray onto the asphalt from a desired location of the sensor	1. Very good protection for sensor 2. Low cost	1. Needs additional equipment 2. Infrared light is not transmitted in mirrors- no reflection	31
<b>Thermal camera</b>	Measurement with camera located inside cabin instead	1. Long range 2. Easy to implement 3. Accurate measurement	1. High cost 2. Takes up space in cabin	NA
<b>Objects in front of sensor</b>	Obstacles for pollution to stick to instead of reaching the sensor	1. Low cost 2. Easy to implement	1. Not reliable 2. Needs additional equipment 3. Needs more room in machine	NA
<b>Removeable plastic foils- manually detached</b>	Plastic foils attached to sensor lens. Comes in many layers and can be removed to apply next clean layer. This version consists of manual removal made by machine operator	1. Low cost 2. Accurate measurement 3. Protects sensor	1. Requires large amount of maintenance- daily 2. Difficult to implement	32
<b>Removeable plastic foils- Automatically detached</b>	Plastic foils attached to sensor lens. Comes in many layers and can be removed to apply next clean layer. This version consists of automated removal of layers	1. Automatic process 2. No maintenance needed	1. High cost 2. Requires additional equipment 3. Requires more power supply- may exceed 24 V	32

Ideas that are generated have the purpose of maintaining temperature measurements that can keep an autonomous system running with minimal interruption. Although some of the ideas lack feasibility and are difficult to implement, they do enhance creativity and allow for further upbuilding of ideas to take place.

## 4.5 Selected concepts

From what was achieved in the brainstorming phase, five ideas were chosen and further developed on to narrow the scope of ideas and initiate proof of concept phase. This initial selection was made with consideration to feasibility, functionality, need of equipment and potential of concept in terms of support for measurement reliability.

#### 4.5.1 Distance and placement

One method with potential to protect the temperature sensor is to distance it from areas vulnerable to condensation, dust, dirt, and liquids. To keep the sensor function is still a crucial aspect. The sensor is not limited in terms of range but consistently decreases in performance when the distance from where it measures is increasing. Optimal spot size which also brings optimal measurement accuracy is achieved at a distance of maximum 150 mm (see Appendix 2, figure 32)

Distance clearly influences accuracy but is not the only parameter that determines the accuracy of the sensor. Placement has a role and can keep the sensor from being polluted if placed where it's not vulnerable to pollution.

##### 4.5.1.1 Current placement

The current location of the sensor is at the horizontal middle of the machine.

It becomes interesting to gain knowledge about the sensor's current distance to the asphalt surface to determine whether it affects the accuracy of the sensor measurements. The distance to the asphalt was measured to approximately 2 meters (see figure 10 below).



*Figure 9: Distance of sensor mount to asphalt.*

A spot size of 233,4 mm is calculated to be the measurement area of the sensor when it reaches the asphalt (see appendix 2 for calculation).



#### 4.5.1.2 New placement – On top of cabin

The concept of distance and location is explored when different placements are considered. Implementing more distance between the sensor and the asphalt surface along with an improved location, where the sensor isn't as reachable by pollution is attempted. Initially, the sensor is intended to be placed on the rooftop of the asphalt roller's cabin. Keeping a minimal angle is important to prevent the target area to hit the hood of the machine. The minimal angle is calculated to 53,13 degrees (see appendix 2).

Placing the sensor on top of the cabin distances it from contact with steam coming directly from the work area, the asphalt. It is a simple solution with potential that doesn't require equipment, maintenance nor power supply. The sensor would be mounted on the cabin, 3 meters above the ground. It results in a larger distance for the sensor to read from which allows for less incorrections (see figure 11 below).

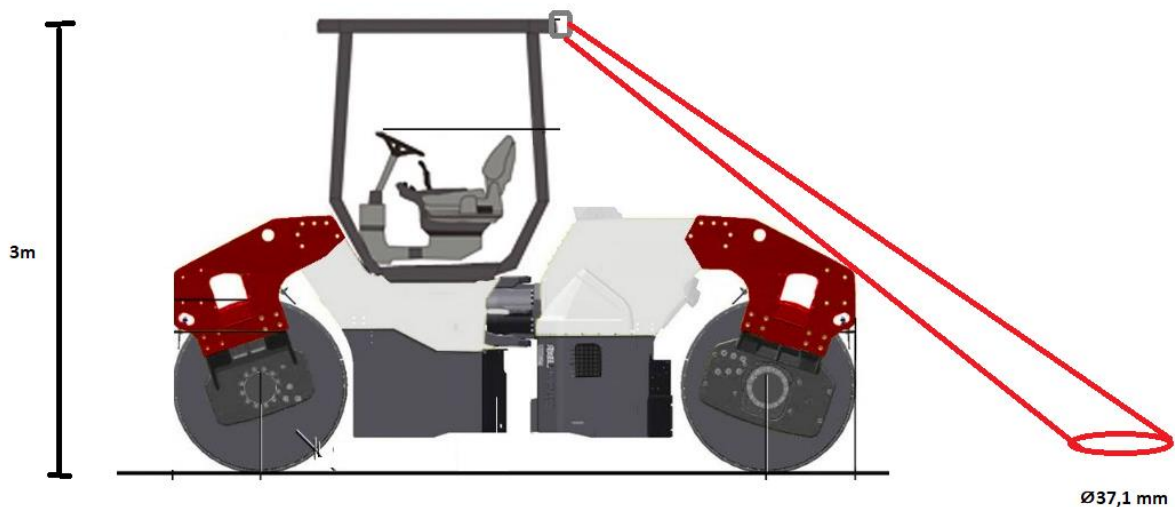


Figure 10: Sensor mounted on top of cabin.

Longer distance with a larger spot size diameter, 37,1 mm in specific (see appendix for calculation) can result in less accurate measurements. Ensuring accuracy is therefore crucial to ensure that the fundamental of the idea works. A test was made by two persons according to the steps below:

- Sensor was tied and hoisted to the ceiling while still being connected to the machine with capability of adjusting distance (see figure 12 below).
- A wheel barrel filled with hot water was used to achieve a larger surface of measurement to decrease the chances of the sensor targeting other areas than the water.
- The sensor was then elevated slowly above the water surface while readings were constantly achieved from machine infotainment.





*Figure 11: Sensor accuracy test at Dynapac's test facility.*

At a water temperature of 50 °C, the sensor showed error margins of maximum 3 °C. After dialogues with an engineer at Dynapac it is evident that the error is negligible. Errors of this size do not affect the system crucially. This validates the potential of the sensor when it comes to measurement from longer distances which strengthens the reliability of the concept.

#### 4.5.2 Thermal camera

Thermal cameras are tools used to identify heat and can record them in the shape of temperature values or images. They, not unlike the current sensor mounted on the machines at Dynapac, measure temperature by collecting data from infrared radiation which runs by a linear relationship to color shown and appears to be brighter contra darker depending on temperature. [27] . It is common for thermal cameras to be found used for surveillance due to their great ability to read from a longer distance. Their use in a wide group of sectors indicate their success in range and target area[28] .Cameras are therefore useful and have relevance within the project.

The idea behind such solution is to benefit from its long range and target area, allowing for a greater spectrum of position in comparison to the current system where the sensor has a small target area and must be mounted targeting areas in front of the drums. Initially, this idea was also very interesting due to the assumption of its ability to read through glass, making it a worthy nominee. Worthy of mentioning is the fact that the glass used in the machines at Dynapac is made out of tempered and laminated glass. Unfortunately, after an investigation through research, it is apparent that both laminated and hardened glass block infrared radiation [29] (see figure 13 below).

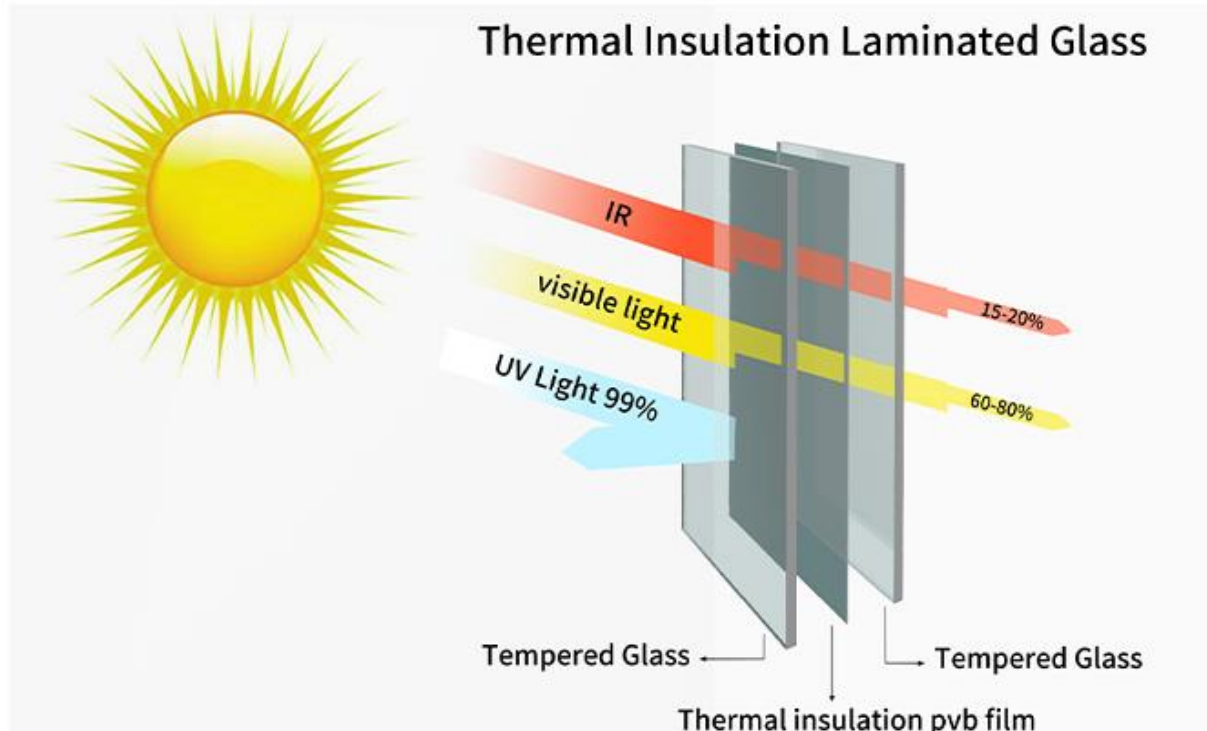


Figure 12: Management of infrared radiation by tempered and laminated glass.

For further assurance, a test was made with the existing infrared sensor. Tempered and laminated glass does in fact block infrared radiation. This conclusion was brought by the inaccuracy of measurement done through the glass cabin on the machine. Instead of reading through the glass, the sensor was reading the surface of the glass (see figure 14 & 15 below) which speaks against the use of a thermal camera unless used outside the cabin.



Figure 13: Direct temperature reading of phone screen.



Figure 14: Temperature reading of phone screen through laminated glass.

Using a thermal camera outside of the cabin puts it into the same condition as the current sensor and therefore takes away its supposed advantage.



### 4.5.3 Nano spray coating

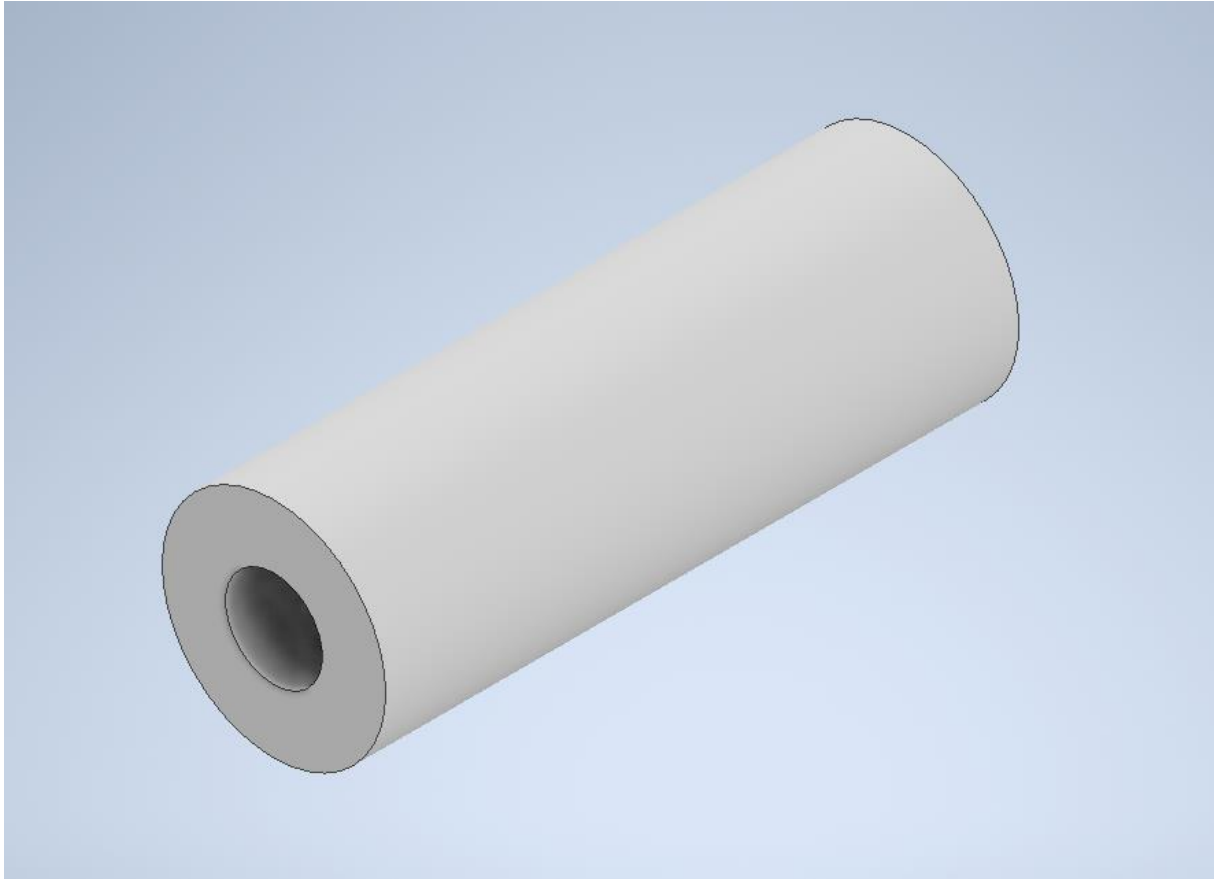
Coatings that make a surface reflect incoming pollutants have a high potential of being one out of other ways to aid autonomous driven systems by assuring uncompromised data captures by sensors. Assumptions were made upon going forward with this concept that the nano coating has an adequate reflective effect while simultaneously being cheap and easy to implement. They do not take up space in the machine nor need supply of electricity and require no maintenance for the performance to be achieved. Research on this topic through dialogue with potential suppliers strengthened its value, with a durability of one to two years after application. Nano coating aids the surface to be less sticky, allowing for liquids to come off very easily. Dialogue with a supplier concluded another advantage which points at low maintenance thanks to the long durability of 1 to 2 years.

### 4.5.4 Replaceable plastic film

Replaceable films that are changed whenever the sensor performance gets compromised due to dirt are capable and can be implemented in versions depending on what kind of equipment that the system is capable of taking, see (appendix 1, figure 34). This can range from manually removed films to automatically removed films depending on the desire of a customer. A manual system would be a major drawback for the concept because of driver interference being crucial. On the other hand, an automatically driven system requires equipment and power supply. It is also difficult to implement within the industry due to the concept's complexity.

### 4.5.5 Lens hiding pipe

With user needs in mind, it is beneficial to approach the problem by hiding the sensor from airflow that leads pollution to the lens. To avoid environmental pollution, distance between the lens and exposure of air is provided. The pollution will find its place on the pipe walls before it reaches the lens to protect the sensor from measurement errors which occur when the lens is covered. A solution such as this is feasible and does not require supply of power, water, and air. It also does not require a large amount of space, nor does it cost much to implement. The concept consists of a cylinder-shaped cover that is mounted to the sensor, creating distance between sensor lens and direct exposure to air (see figure 16 below).



*Figure 15: Lens hiding concept in Autodesk Inventor*

The pipe can be designed with different inner hole patterns. Simple patterns make up for a more feasible product although the concept itself is easy to manufacture. Materials that are to be used vary depending on customer and context. Stainless steel, plastic with high melting temperatures and aluminum are convenient choices thanks to price consideration, formability, and weight.

#### 4.5.6 Concept ranking/selection

Concepts are put against each other in terms of performance, cost, feasibility and need of maintenance for evaluation. All five concepts will be evaluated and compared to identify the most promising ones from a customer needs perspective but to also narrow down the prototyping phase by eliminating two concepts. Pugh's matrix [17] is used for concept evaluation (see figure 17 below).

		Alternatives					
Criteria	Baseline	Current : Cm sensor mounted above drums	Reloaction	Nano-spray	Removable plastic film	Sensor lens mounted further inside	Thermal imaging camera
Minimal maintenance	4	-	+	0	-	0	+
Feasibility	3	+	+	0	-	+	+
Precision of measurement	4	-	0	0	+	+	-
Oil, water and dust resistance	5	-	0	+	+	+	+
Low cost	3	0	0	0	0	0	-
Light adjustability	4	+	+	+	+	+	0
Voltage of maximum 24 V	5	0	+	+	+	+	0
Functionality	4	-	+	+	+	+	+
Convenient size	3	+	+	+	+	+	0
Less need of equipment	5	0	+	+	-	+	0
Material waste	2	+	+	+	0	+	0
Totals		-1	7	6	3	8	2
Rank		6	2	3	4	1	5

Figure 16: Comparison of chosen concepts with Pugh's matrix.

As seen in figure 17 above, hiding the sensor further up has an advantage over the other concepts. Not only does it have independence on maintenance and a low need of equipment which meets the customer needs. It also allows for temperature measurement that is minimally compromised by surrounding environment, ensuring that an autonomic system can be established.

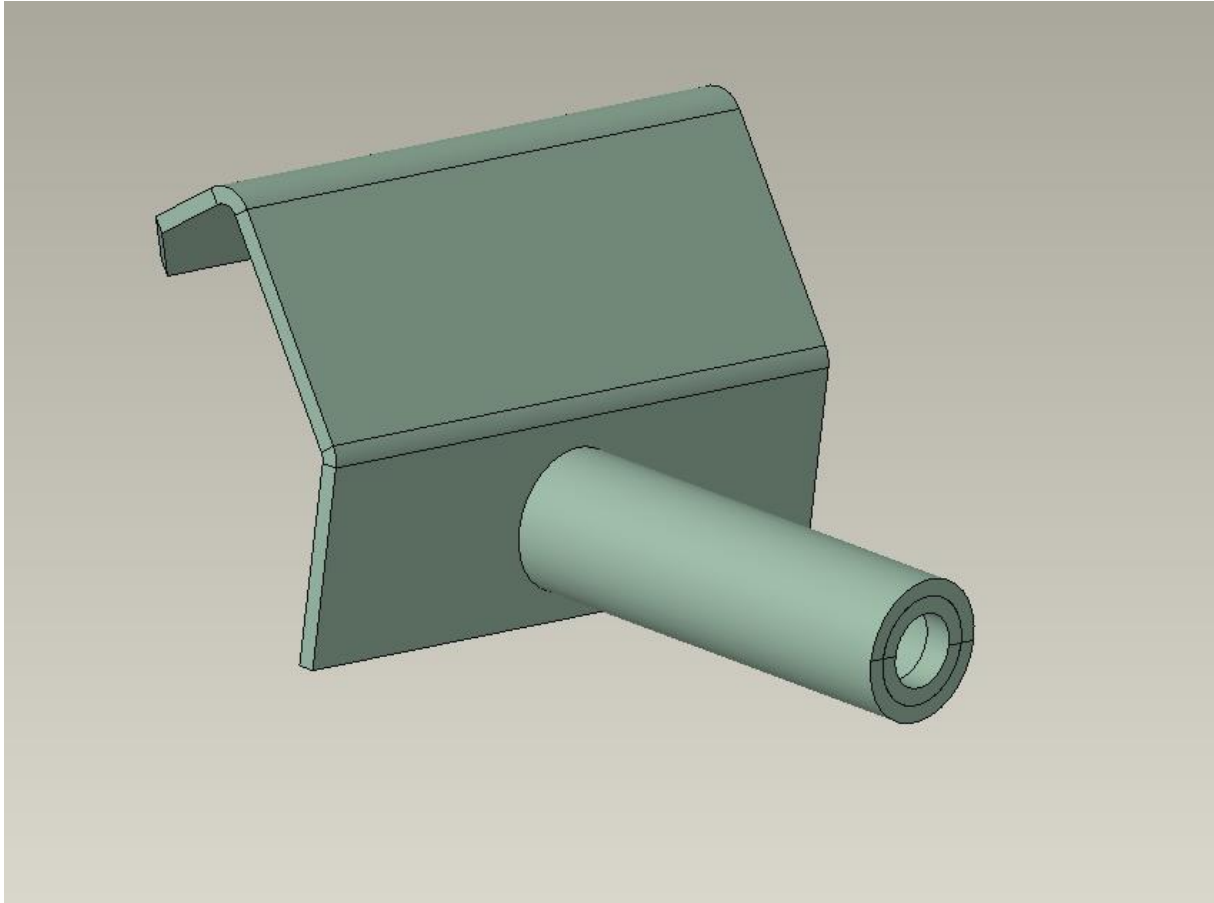
Unlike the 3 highest ranked concepts, the thermal camera and the removable plastic film concept show deficiency in key aspects which are precision of measurement and maintenance. A need of equipment along with low feasibility for the removable plastic film categorizes it further down with respect to user needs. The thermal imaging camera displayed a strong disadvantage without its capability of reading through glass which was the foundation of the concept. Apart from the already mentioned disadvantages around the thermal imaging camera, its cost put it further down in the ranking. The removable plastic film and thermal imaging camera will therefore be eliminated and left for discussion later in the project.

## 4.6 Prototyping & testing

Three concepts were to be tested with four different prototypes made, one of which represents the distance and replacement concept, two covering the lens hiding concept consisting of pipes and one covering the nano coating concept. All concepts were then tested at the same time in conditions relevant to what each concept's corresponding final product would have to endure.

### 4.6.1 Distance and replacement

A prototype design of a holder for the sensor to be mounted in level with the cabin roof was made. The mount was made in Autodesk inventor with the purpose of being 3d – printed. The sensor will be placed at the roof inside a mount with an angle of 54° (see figure 18 below).

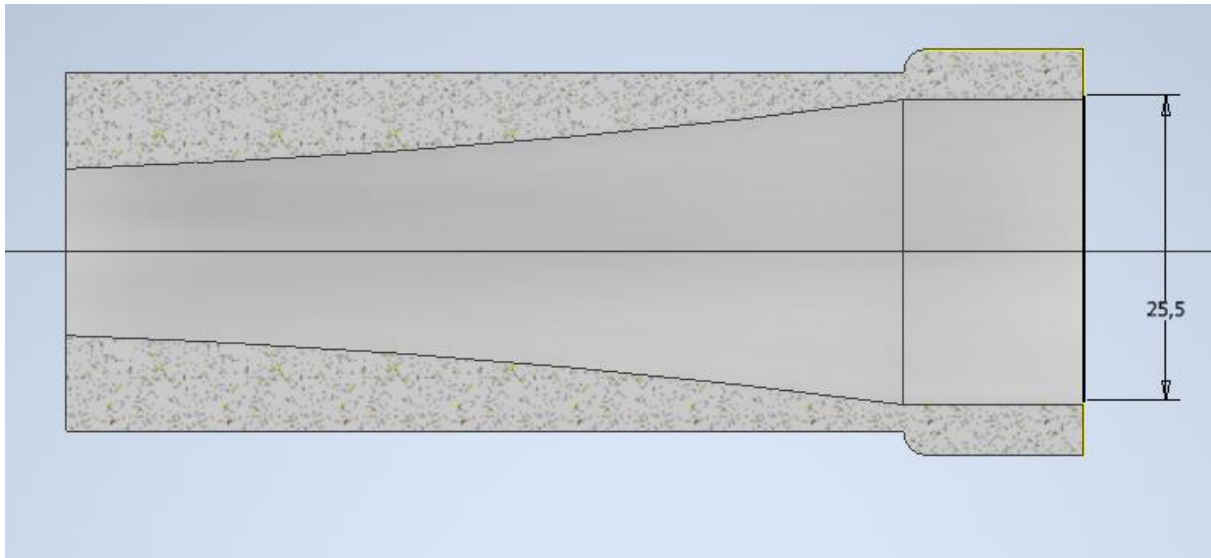


*Figure 17: Roof mount for sensor created in CREO.*

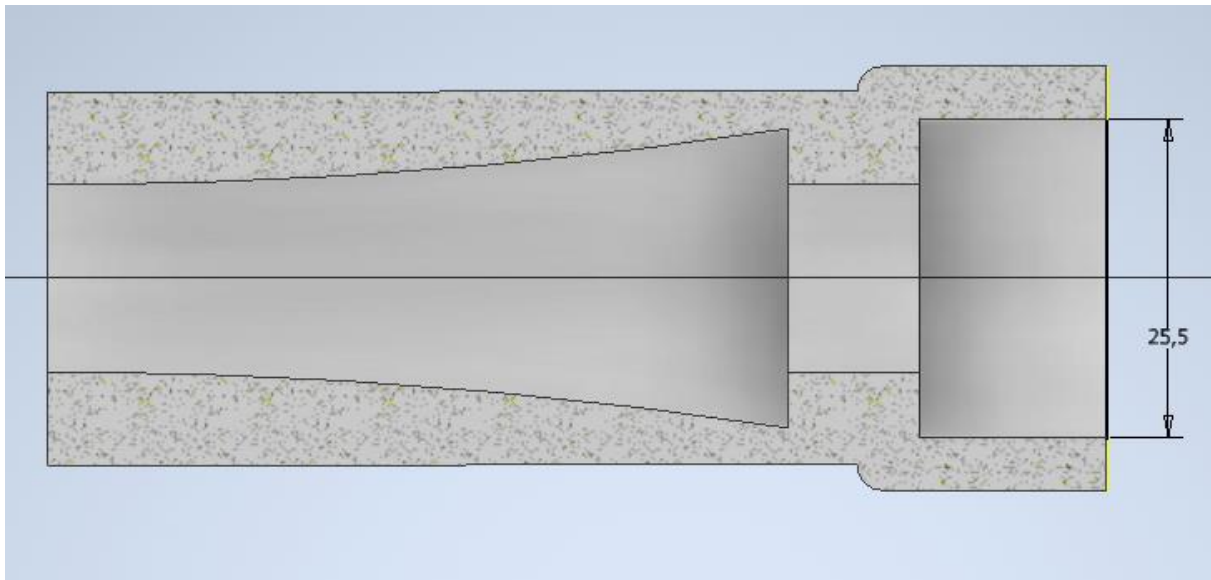
A roof mount with a 54° angle allows for concept testing of the distance replacement concept. With a 54° angle, the sensor is placed where it can measure the temperature of the asphalt and not be directed towards the asphalt compactor components that otherwise would be in the way.

#### 4.6.2 Lens hiding pipe

Two pipes have been constructed. Both are to serve the same purpose which is to distance the sensor lens from contact with flowing air that carries pollution. The pipes are created with different hole patterns to test the concept but to also evaluate whether different patterns can contribute to the performance of the temperature measurements. To distinguish between the pipes, they will be presented by the names pipe 1 and pipe 2 (see figure 19 & 20 below).



*Figure 18: Pipe 1 constructed in Autodesk inventor.*



*Figure 19 : Pipe 2 constructed in Autodesk inventor.*

The pipes are both created and 3d-printed with an outer diameter of 34 mm and an inner one of 25,5 mm as seen in figure 19 and 20. The reason is for a 25,5 mm cylinder with a thread to be glued inside the pipes. A thread is applied for the cylinders to be able to fit a sensor with the same thread.

#### 4.6.3 Nano spray coating

This concept was simple to implement for testing and only required a coating to be obtained which was ordered to Dynapac in the shape of a liquid spray that goes by the name BriteGuard PRO (see figure 21 below).





*Figure 20: Nano coating used for sensor application.*

Before the testing phase, one sensor was cleaned to be used for application of nano coating which was made according to instructions on the packaging that was provided by the supplier.

#### 4.6.4 Testing and results

Efficiency in terms of cost and time was considered for the testing. It was to be achieved by testing all the concepts at once. Five sensors would be tested, one of which would be mounted on the roof and the rest within the same area as the previous sensor placement which is where these concepts would be applied if they were to be developed as a final product. A sensor mount that can carry four sensors was developed in CAD. It was then manufactured in Dynapac's workshops and consisted of stainless steel to be able to hold the weight of the sensors. Simultaneously, a roof mount was constructed in PLA through 3d-printing, both holders are seen in figure 22 below.



*Figure 21: Sensor mounts for prototype testing. At the left, a mount for four holders. At the right, a sensor mount for the roof.*

Sensors were successfully mounted into their holders. Both mounts were then installed on one of the asphalt roller compactors at Dynapac (see figure 23 below).



*Figure 22: All concepts for testing are mounted on a roller compactor at Dynapac.*

Certain weather conditions are crucial to assure a testing session that puts the sensors into an environment that can challenge the concept's abilities to protect the sensors from pollution. The tests were therefore planned to be on a warm day without rain which helps pollution to be dispersed unlike

on a rainy day. Tracks for testing were used at Dynapac to perform the tests. Instead of asphalt, the tests were made on a surface of sand and gravel due to the availability at Dynapac (see figure 24 below).



*Figure 23: Concept testing at Dynapac's testing tracks.*

Gravel and dust were the testing condition which caused a large amount of pollution as seen in figure 24 above. Thanks to the conditions, the concepts could be compared to each other in terms of pollution resistance and ability to prevent measurement errors caused by debris. A total testing run of 4 hours with occasional breaks for concept validation was executed. Initially, the test was run for 30 minutes, and an additional run of 120 minutes. Finally, the machine was ran for another 90 minutes concluding a 4-hour long test run. Warm water around 50°C was used within the validation to have an area of measurement with higher temperature. A calibrated temperature handgun was used to as a reference for correct temperature values. Results are presented with Celsius as te in table 5 below where referenced values are expressed in parenthesis.

Table 5: Test results for each concept.

Total testing time and error margin	Previous concept (reference)	Relocation concept	Pipe 1	Pipe 2	Nano coated sensor
Temp after 30 minutes (Celcius)	45 ° (50°)	50° (50°)	50° (50°)	49° (49°)	54° (55°)
Error margin	10%	0%	0%	0%	2%
Temp after 150 minutes (Celcius)	53° (50°)	37° (37°)	50° (50°)	50° (50°)	52° (50°)
Error margin	6%	0%	0%	0%	4%
Temp after 240 Minutes (Celcius)	39° (47°)	45° (44°)	42° (42°)	45° (45°)	44° (46°)
Error margin	17%	2%	0%	0%	4%

The prototyping and testing was made to evaluate each concept's performance in terms of maintaining accurate temperature measurements made by the sensor to assure a successfully operating autonomous system. It is apparent that the error of measurement is proportional to the amount of time that the sensors run for. Developed concepts show improvement compared to the reference system. The lens hiding pipe concept shows the most promising results with no compromise in measurement performance after 4 hours of testing. On the other hand, the relocation concept showed a small deficiency after the testing session was finished. Coating a sensor shows to be helpful to an extent but is not a bullet proof approach considering the results shown in table 5. Already after 30 minutes, a small error was recognized although not severe.

Keeping in mind that the lens hiding pipe has the highest potential when it comes to meeting customer needs, its accuracy in measurement that is proven through testing is a worthy addition which makes it the choice of final concept in this project.

## 4.7 Business model

The concept's success comes from its ability to generate revenue which will be discussed in this part with the use of a business model canvas. Once the concept is chosen, a business model canvas is created to map the business model that the product will follow to establish a market success. Business model will be created under the terms that a company responsible of the concept exists.

### 1. Value propositions

Function without necessity of power supply nor compressors, water, and detergents. Maintenance will be minimized, allowing for autonomous systems dependent on temperature measurement by sensors to run without user interference. The solution comes at low cost and can be adjusted into an easily implemented feature. It is an addon feature that can be installed

and removed without complexity, making it independent to the design of the vehicle it's built for.

## 2. Customer segments

This concept targets customers within the construction industry with mobile vehicles that have a limited amount of room and equipment to work with. Having no need of power supply for an additional feature benefits such vehicles due to their limited capacity when it comes to space, power supply and fluid tanks.

## 3. Customer relationships

Designs will differ depending on sensors along with different companies having a variety of sensors. A crucial relationship is to be constituted between design company and construction companies for cooperation regarding the construction of the concept due to its wide variety in looks and size.

## 4. Channels

The concept will be designed and installed for machines according to their build and dimension. Differences can occur between customers, and they will be neutralized by individual service.

## 5. Revenue streams

Since the concept is a product that is delivered to customers, each product will make its revenue through its own sale. It is crucial to keep in mind that the success depends on the amount of sold examples.

## 6. Key activities

Customer service, to gain knowledge about each customer's machine and adapt the solution to it. While a generalized solution may still have potential, an individualized product is important to optimize its value.

## 7. Key resources

Collaboration between the designing company and its customers, to create an as desirable product as possible.

## 8. Key partnerships

Customers, to learn about the machines on which the concept will be installed.

## 9. Cost structure

Manufacturing of the concept is what makes the base of the cost. Everything from individualized holders to covers will be included. Sets of tools to build the concept is included here as well, where labor, factories and electricity are also no exception to the cost.

## **5 DISCUSSION**

The project work has been done within a time frame of approximately four months and the results are discussed below.

### **5.1 Identified demand**

The early stages of the project were devoted to needfinding which took place at Dynapac. Interviews were held with people from the company, making the focus slightly biased to Dynapac's. On the other hand, the interviews were made with people of different expertise and roles such as mechanics, service managers but also engineers of different background which covers input from a variety of competence and experience.

Since the compactors revolve around asphalt work, it could be argued that this specific context should be observed. Additionally, it would be helpful observe how long it takes for the sensor measurement to be compromised by pollution. Such observation was not possible to make keeping in mind that asphalt compaction is not performed during wintertime because of low temperatures. On the other hand, this specific data was extracted through interviews that still established information regarding the timespan of which lens cleaning is needed. This data was then translated into how long it would take for the sensor to be critically polluted.

Product requirement and criteria had large weight on solving the problem while also sticking to the project's delimitations. It allowed for a structural product development while simultaneously following customer needs, partially thanks to delimitations being introduced early in the project.

### **5.2 Stakeholder analysis**

Identified stakeholders have been stated according to their relevance to the project. Their impact has on the other hand been analyzed according to each of the stakeholder's ability to change the outcome of the product's result. Governmental input is very important and determines whether the product is allowed to be used. Their relevance is amped up by their interest within the product due to construction machines having a large proportion of their customers operating within government interest. Customers and direct users of the product are Dynapac and competitors that may find interest in the product are therefore of relevance as well.

Mechanics and drivers have direct contact with the potential product and problem where the driver is the primary user of the product. Mechanics are those who deal with its maintenance. Their relevance is high, not unlike the driver. On the other hand, their input in terms of power is not high. However, thanks to their experience and knowledge in the problem stated, their influence to the project in terms of information about pain points argues for their importance.

The project's Approach for stakeholder analysis has been of great use with a simple overview of what kind of people to revolve around the product development. However, the combination of both a stakeholder salience map and a power-interest grid map can seem contradicting regarding different statements that can be made about certain stakeholders in both approaches. On the other hand, the two different tools are of good use thanks to their ability to compensate each other with information.

### **5.3 Concept selection**

Replacing the sensor to be higher up, specifically at the top of a construction machine is deemed to be not only efficient, but also manageable thanks to small compromise in data capturing due to longer distances to surface. It will yet not be very protected from its surrounding although



it avoids closer contact with it. It could also be argued that the feasibility of the concept is very high. A simple sensor mount is everything needed to apply the concept which makes it promising for the construction industry.

Thermal cameras suffer from a bottleneck in its inability to read through glass cabins. On the other hand, it can be mounted outside, at the top of the cabin but it loses its purpose which was to be secured inside a cabin. The thermal camera then loses its supposed advantage. This also puts it into the same circumstance as the sensor replacement concept which was proven not to be critically ruined by distance. This is a large drawback considering the high cost of the camera.

Nano coatings supposedly offer a strong performance, helping pollution come off surfaces and have good reputations within vehicle industries. Without testing their relevance within harsh environments due to lack of time and resources, it is difficult to assess their performance. It can also be argued that the claimed durability of 1 to 2 years is not reliable. This would need to be tested and is therefore left for future works. Steam coming from oils and sticky liquids may be of difficulty for the coating to deal with. Steam of such character is for example created when asphalt condenses. This circumstance was unfortunately not possible to create at Dynapac and is therefore not studied in this project.

The Replaceable plastic film concept suffers from a sustainability issue caused by plastic waste which occurs when films are replaced occasionally. It creates waste and pollutes the environment. Such concept also needs individual designing of the plastic films, requiring a relevant supplier which is costly. Manually removeable films brings back the problem of needed maintenance by driver which is to be avoided in this project and lowers the value for such concept. An Automatically driven system is promising performance wise and removes all need of maintenance. However, it is important not to ignore that such system requires power supply and equipment which holds the concept back along an increasing cost.

A lens hiding concept offers protection of lens, preventing dust from entering and covering the lens. Besides, it is still a very feasible product unlike examples seen on the market that require supply of equipment, electricity, and water. It also comes with potential to forestall compromised measurement. It is also worth to mention that the temperature can increase inside the pipe which can alter the measurement accuracy. This is to be found through further testing. It can also be argued that the feasibility may be lowered due to formability depending on inner hole patterns. However, this can be altered and refined depending on possibilities for manufacturing. Additionally, the concept can be altered into being a throwable plastic pipe, where a new pipe can be installed easily and the used one thrown away. This approach is on the other hand less sustainable and creates waste which lowers the value of the solution.

## **5.4 Prototyping and testing**

Placement on top of the machine was a feasible approach. It can be argued that the sensor should have been placed at the middle. however, it would have required modifications in the shape of new holes on the cabin for the sensor to be mounted. This is to be seen as part of the prototype where the exact location would be the final product. Looking at the concept from a perspective of performance, it supports the sensor with protection that aids accurate measurement.

The pipes were identical to the final intended product in terms of design. Potential changes could be the choice of material along with internal patterns which can vary. The prototype therefore tested the functions of the concept properly. Distancing the lens and making it less vulnerable to dispersed pollution was therefore tested successfully. Internal patterns applied in the two prototypes were different but displayed the same level of performance with no errors of

measurement. For further evaluation of pattern differences, it could be argued that longer periods of testing are needed to be executed. This concept allowed for no pollution to impact sensor measurement. An autonomous process with dependence on temperature measurement is deemed to be supported by this solution.

Applying the nano coating on one of the sensors was a simple procedure but can be a source of potential error when looking at the test results. The sensor lens consists of a small area. Application of nano coating therefore came with a difficulty which strengthens the argument for it being a source of error. This concept allowed for an improved measurement accuracy in comparison to the original sensor condition. On the other hand, it showed the least promising results upon comparison with the other concepts. An improvement still shows support for autonomous systems and therefore dictates a valid approach to the problem.

Although the temperature handgun was calibrated, it may still have had margins of error which could have impacted the results. It can also be argued that a more stable or that an even higher temperature could have been used. Equipment that allows for such context was not available at Dynapac. However, the results were still able to map out the performance of each concept. Each of the concept's ability to support autonomous systems was able to be addressed and evaluated making the test adequate for the application.

The lens hiding pipe concept was in the end chosen as the established final concept for the project. Prototyping and testing results were a good base for this conclusion to be drawn. However, the customer needs that are also visualized within criteria proposal is the second and final argument to why this concept is chosen. Not only does the lens hiding pipe allow for accurate measurements to be made, it is also chosen to meet customer needs which it does in a better manner compared to the other concepts.

Worthy of mentioning is the opportunity to combine some If not all the concepts. Every concept displays success in supporting an autonomous system through improved accuracy of sensor measurement. This indicates possibility of further improvement if needed.



## 6 CONCLUSION AND FUTURE WORK

How may Infrared temperature sensors be protected by pollution in order to improve autonomous systems?

Improving accuracy of temperature measurement can be made with a wide variety of approaches and different levels of complexity. However, it is evident that accuracy of data measurement has a large impact on autonomous systems. Focusing on temperature measurement within construction equipment machines, it is crucial to consider mobility as a drawback in terms of resources. Measurement is critical for autonomous systems to run properly which concludes a need of a solution with minimal amounts of equipment, supply of power and water. This is while also eliminating the maintenance needed for the system to properly operate.

A solution in the shape of a pipe to be mounted on the sensor has been established and validated. It decreases the sensor's vulnerability to pollution and is achieved thanks to the added distance between the sensor lens and direct contact to air.

A final concept consisting of a sensor pipe to distance the sensor lens from exposure to dust, air, oil and steam of different kinds comes with the following benefits:

- Improved measurement accuracy
- Reduced need of maintenance
- Supports autonomous systems
- Low cost
- No need of equipment supply
- Hiding the sensor lens is a general solution and pipes can be constructed to fit all kinds of systems with this problem at hand.

It has been concluded that the research question has been answered through distancing infrared temperature sensors from the working area and flow of air which transports debris eliminates their vulnerability to compromised measurements. While being feasible and mobility friendly for construction equipment, it supplies autonomous systems with correct measurements which improves a system's behavior, therefore also resulting in better fuel and energy efficiency.

### 6.1.1 Future work

The lens hiding pipe concept can be put into further testing to evaluate other aspects revolving around the concept. This regards whether the concept needs to be maintained and if so after how long. It is also important to state the need of further testing to ensure that an increase of temperature inside the pipe does not happen.

It is also beneficial to reach out to external customers for tests that dure for long periods to gain a wider perspective of what works for the sake of the research. The concept can then be approved to be marketed and used within any industry in need of sensor protection.

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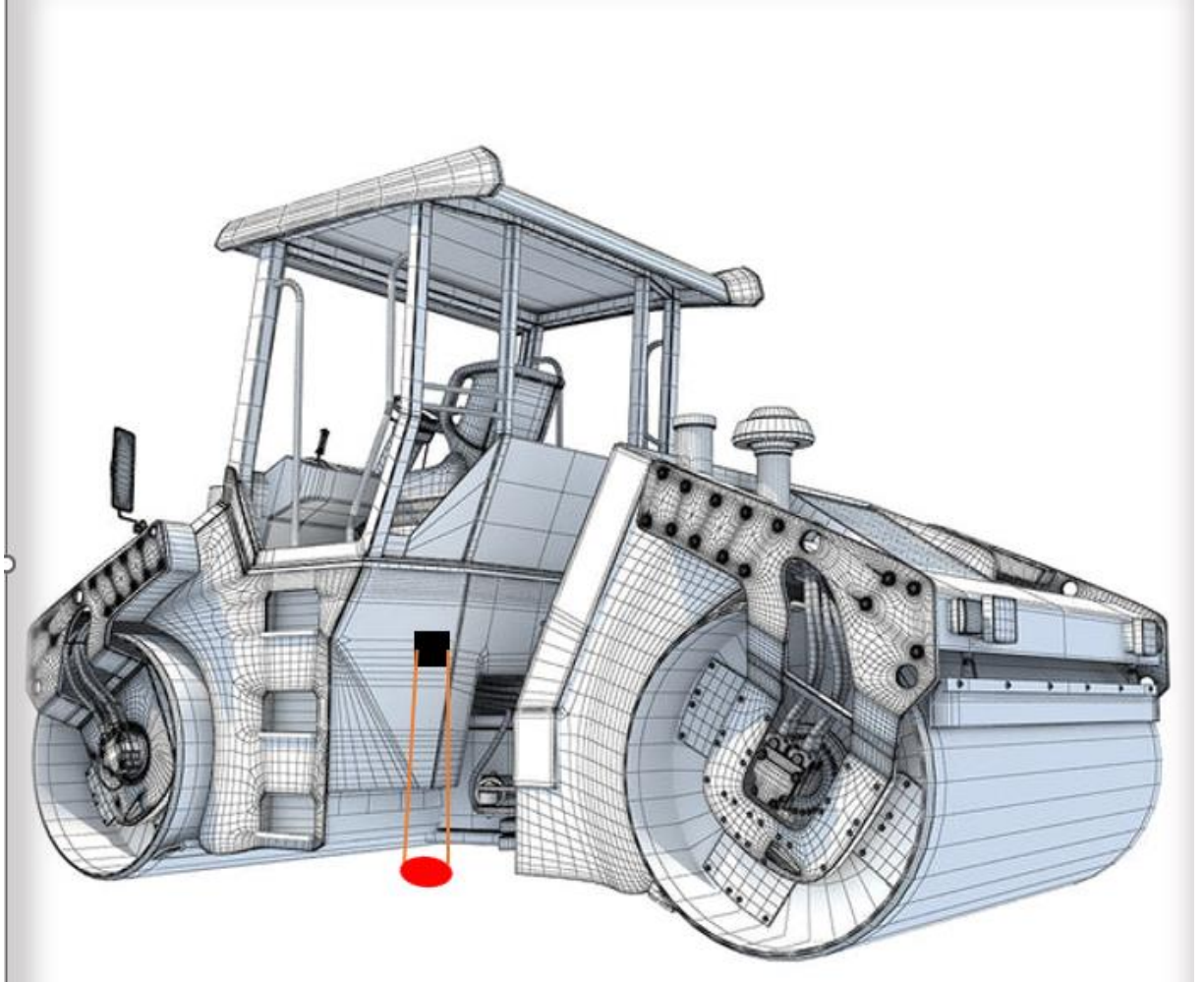
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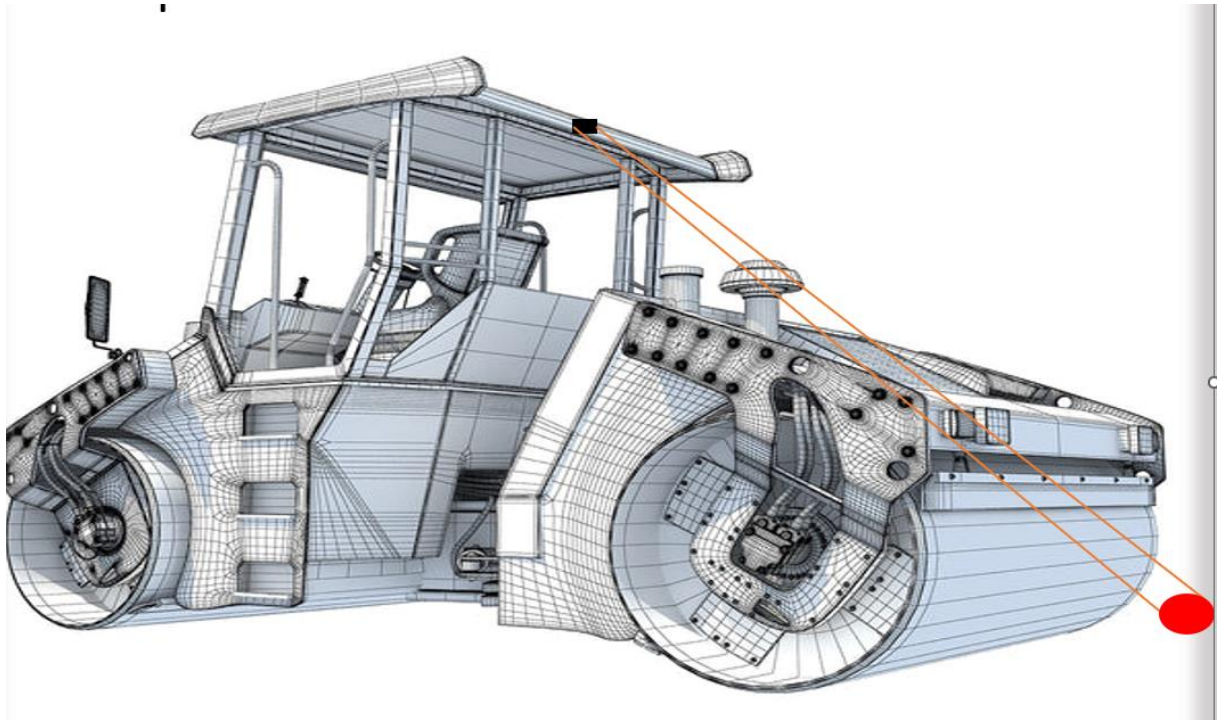


## 8 APPENDIX

### 8.1 Appendix 1: Brainstorming sketches



*Figure 24: Sensor placement between drums.*



*Figure 25: Sensor placement on top of machine, mounted on cabin.*



*Figure 26: Temperature stick.*

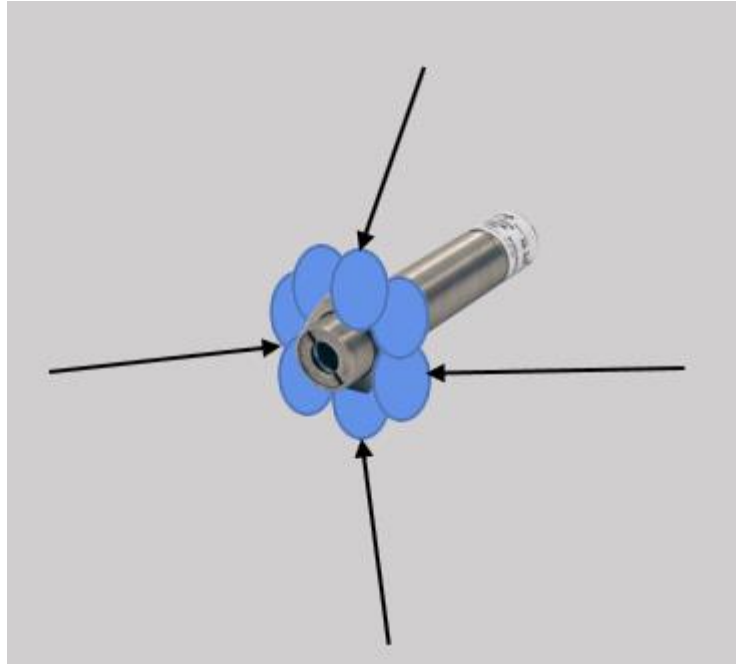
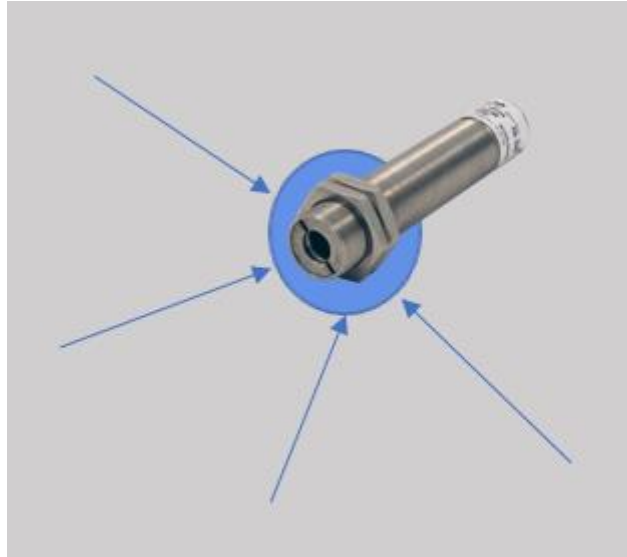


Figure 27: Vacuum cleaning system



Figure 28: Water and soap with air blowing system, adapted from [30].

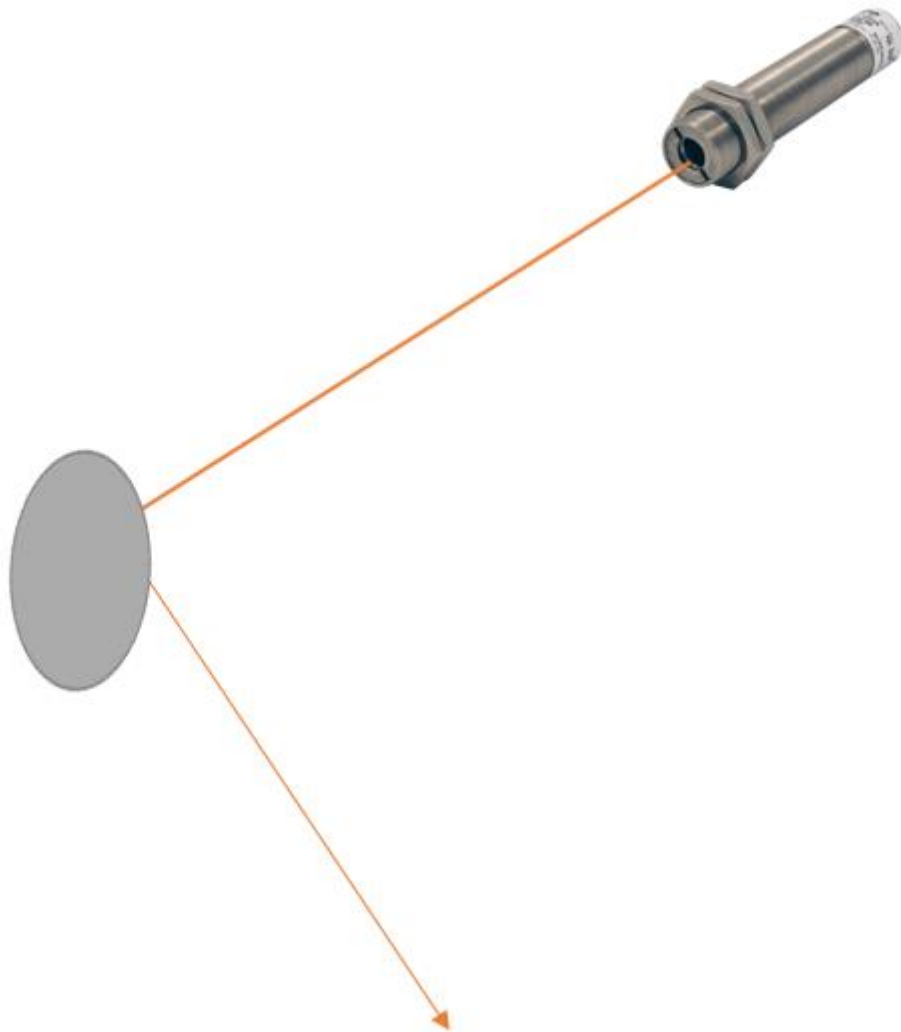


*Figure 29: Magnetic cloth absorbing dust.*



*Figure 30: Protective window to protect sensor lens from pollution.*





*Figure 31: Mirror angling*



Figure 32: Plastic removeable foils in the shape of "tear offs" used in motocross, adapted from[31].

## 8.2 Appendix 2: calculation of CM sensor spot size

The spot size depends on reading distance from sensor and is presented is shown in the figure 33 below [32].

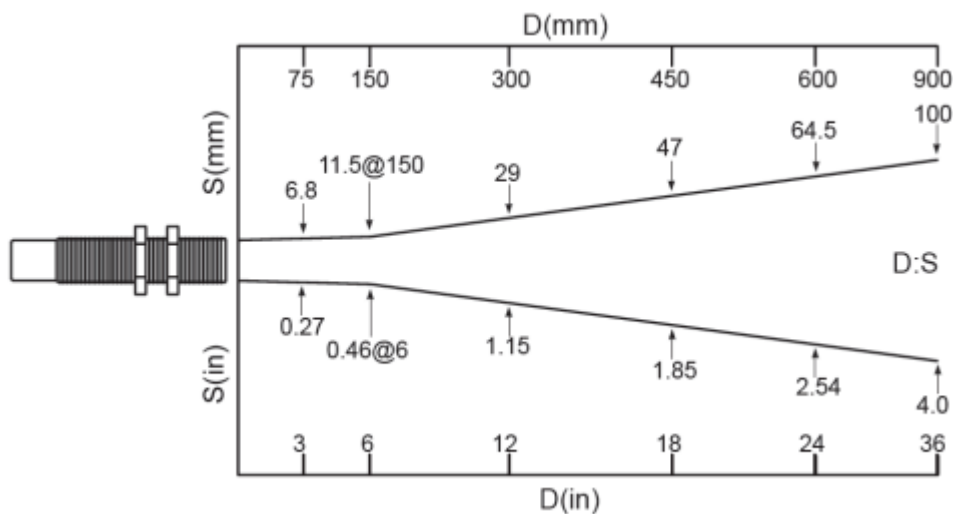


Figure 33: Spot size pattern for current sensor.

Spot size starts to increase proportionally after 150 mm, at 11,5 mm of spot size as shown above. Correlation is seen between distance and spot size. It can be calculated by using other lengths and spot sizes, with a verification of the assumption being made:

With a being length and b being the spot size diameter , choosing 300 mm of length and 29 mm of spot size diameter, a correlation is found :,

$$\frac{a}{b} = \frac{300-150}{29-11,5} = 8,57 \quad 1.$$

Spot size calculation for original mounting position:

$$\frac{2000}{8,57} = 233,4 \text{ mm}$$

Spot size calculation for sensor mounted on top of machine :

$$\frac{3180}{8,57} = 371 \text{ mm}$$

### 8.3 Appendix 3: Calculation of dimensions for sensor location on top of machine

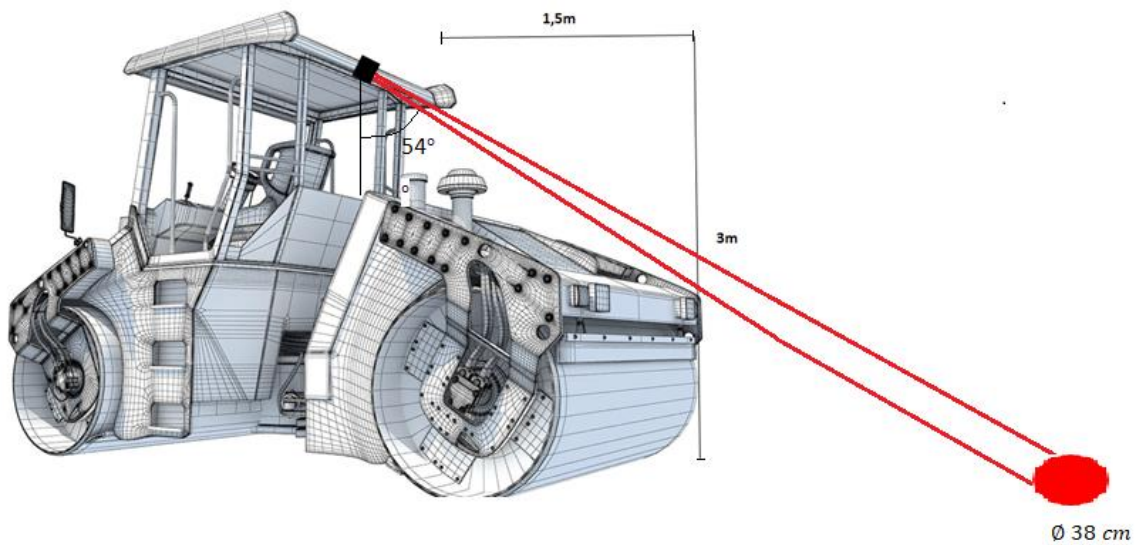


Figure 34: Calculated dimensions created by roof placed sensor.

To calculate the angle of which the sensor has to be mounted, data for the dimensions were achieved through a cad model of the roller (See figure 32 below).

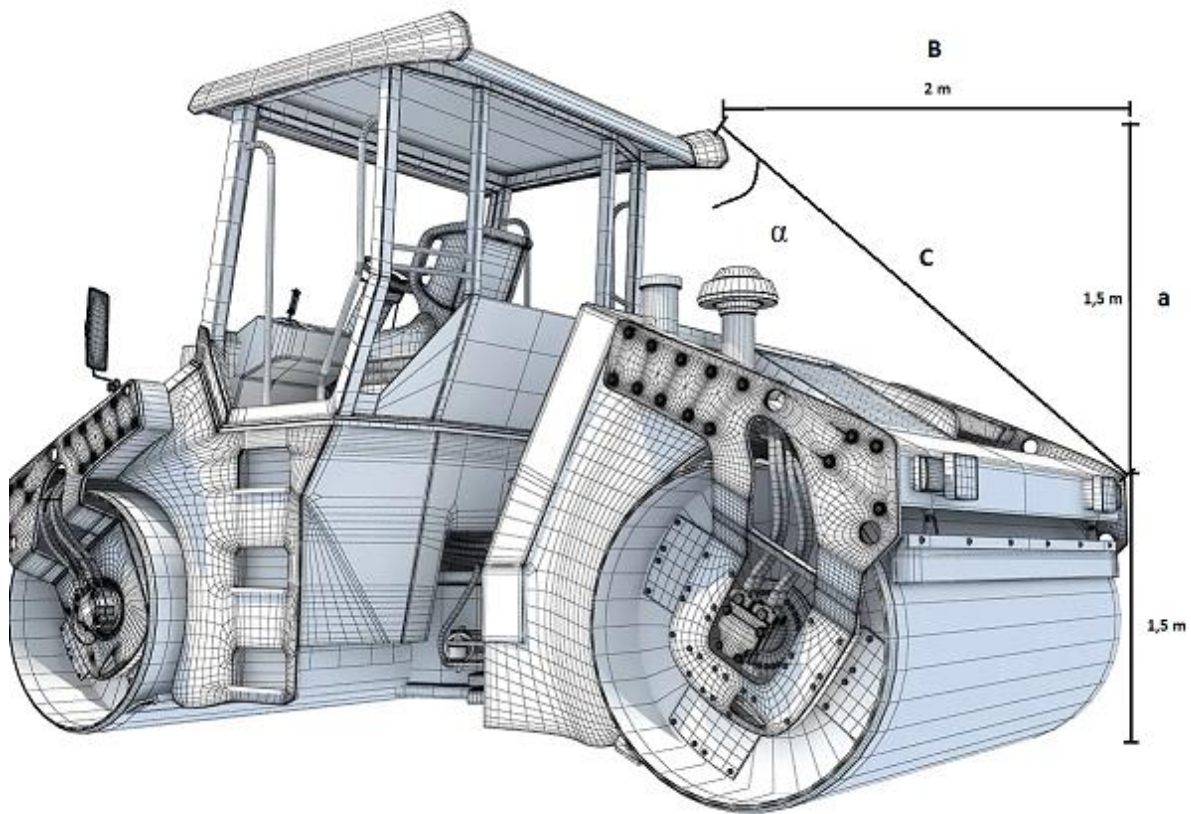


Figure 35 :Sketch of dimensions ((this is not the actual machine))

With the dimensions shown in figure 33, obtained by CAD sketches at Dynapac , keeping in mind that the sensor beam shall have a free path to the asphalt, a geometrical formula allowed for the angle to be calculated :

$$\tan \alpha = \frac{c}{b} = > \alpha = \arctan \frac{c}{b} = \arctan \frac{2}{1,5} = 53.13^{\circ} \quad 1.$$

The spot size of the sensor creates a larger spot diameter as the distance increases which has to be taken into account when choosing angle of mount. The spot diameter change in spot size has already been explored (see appendix 2).

