Effective production and automated processes in road construction

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Abstract
This is a bachelor thesis in the course Industrial Automation, PPU301, commissioned by Volvo Construction Equipment in Eskilstuna.

This thesis treats how we can increase the effectiveness of production in roadside construction through automation. The report presents different concepts of automation and in the end of the report you can read about the concept I recommend and why.

The work has been divided into different stages. In the first stage I have collected information by reading articles and by site visits. The black top process has been identified though a storyboard. The focus is on which machine that would benefit the most from automation.

After identifying the process and the customer’s needs, I get a clear view of what the machines should be able to do. After studying both the paver and compactor, I decided to focus on the compactor. There are significant potential for further development of the compactors in regards of automation. I will present a concept of a totally autonomous compactor.

The compactor must, among other things, be able to position and identify objects, like machines, workers and other road users. The compactor needs to get a clear signal when the road piece is finished with compaction. The packing operation is automatic controlled depending on the type of mix of asphalt, thickness and speed.

There are different solutions to make the compactor autonomous. In the report, I have detailed the different concepts and the sensors needed to realize an autonomous machine.

**Keywords:** Road construction, asphalt, automation
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1. Introduction

Volvo CE, a business area within the Volvo Group, is one of the world’s leading manufacturers of construction equipment producing products such as wheel loaders, excavators, articulated haulers, road development equipment and compact equipment. Volvo today possesses a market leading position in the construction equipment industry in fuel efficiency, productivity and environmental care.

It is expected that the market for automation of construction machines will continue to grow. In order to secure the functionality and reliability for future automation solutions, considerable research and development efforts are needed.

One area with important potential is automation in road construction. The work situation at roadside construction is complex and dynamic, involving numerous machines, such as pavers and compactors as well as workers. It is costly with high demands on productivity and efficiency. The quality of the road and asphalt is essential and it depends on the paving process. Hence, investigation of the possibilities to increase productivity with autonomous functionalities is of great interest.

1.1 Aim of project

The objective of this thesis is to investigate the possibility to make the production in roadside construction more effective with automated processes. The aim is to collect information, identify the black top process and identify the needs of the customers. The material should then be analyzed and the machine that would benefit the most from automation will be developed in concepts. The objective is to make concepts that will correspond to the needs of the customer.
1.2 Project directives
The work will be done by studying the processes at site as well as performing interviews and reading literature. It is essential to be aware of the process and important factors to ensure high quality paving. The collected information should be analyzed and conclusions should be drawn on areas that would benefit most from being automated in order to boost productivity at the site. For the automation areas, concepts and suggestions should be developed on how this can be done. The results and conclusions will be summarized in the report including recommendation on continued work.

1.3 Problem statement
This investigation should provide an answer to the following questions:
- How can we increase the effectiveness of production in roadside construction through automation?
- Can this be accomplished while maintaining safety and productivity?

1.4 Project limitations
The scope of the project is limited to the black top process including both machines used, i.e., paver and compactor. The main reason for this limitation is the time constraint of ten weeks. Consequently, focus has been on the machine that would benefit the most from automation. In the end, a concept of an autonomous improvement model will be presented, without technical solutions.
2. Solutions methods

This chapter will treat the different solutions methods I have used in this project.

2.1 Project planning

The planning is an important part of a project and I felt it was important to choose tools that are easy to follow and easy to work with.

2.1.1 Gantt chart

A Gantt chart is a simple planning tool and provides a visual overview of the entire work. It shows the order in which the tasks should be implemented and whether certain tasks can be performed in parallel, (Gantt Charts).

It is important that, as the project progresses, The Gantt chart should be constantly updated with information about the actual time taken for the various tasks. Gantt chart also provides valuable information for future projects because it shows very clearly how good the original planning was in line with the outcome. The Gantt chart for the project can be found in appendix 1.

2.1.2 Requirement specification

A requirement specification is important to develop in order to be able to agree on what is expected between the client and supplier and also to provide a unified picture of the work. This document has many advantages as it contains the main product requirements and gives everyone involved, a clear picture of the project goal, (MicroTools INC). In appendix 2 the requirement specification for this project can be found.

2.2 Storyboard

A storyboard is a visual story of a verbal idea. It can be compared to a low-resolution movie, where the resolution is determined by how much action there is in the stage. Today, storyboard is commonly used as a planning tool for the film industry. There are many reasons why they use storyboard;
- Supports planning
- To highlight problems
- Create a mutual understanding of problems
- Give visual information
- Evaluate ideas
- Places the user at the center (Wikström, 2012)
2.3 Design thinking

“Design thinking is a human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success.” - Tim Brown, president and CEO for IDEO.

IDEO is an award-winning global design firm that takes a human-centered, design-based approach to helping organizations innovate and grow.

Design thinking brings together what is desirable from a human point of view with economically viable and technologically feasible requirements. It also allows people who are not trained as designers to use creative tools to address a vast range of challenges.

Design thinking process has three spaces to keep in mind: inspiration, ideation and implementation. These three spaces work as a system of overlapping spaces, as shown by my interpretation of IDEO’s Design thinking in Figure 1. The first space, inspiration, is the problem or opportunity that motivates the search for solutions. The second, ideation, is the process of generating, developing and testing ideas. The third space, implementation, is the path that leads from the project stage into people’s lives, (IDEO).

![Diagram showing the three spaces of design thinking: inspiration, ideation, and implementation.](image-url)

Figure 1. My interpretation of IDEO’s Design thinking.
2.3.1 Inspiration

- Problem statement
  What is the business problem? Where is the opportunity?
- Look at the world
  Observe what people do, how they think, what they want and need.
- Sort and structure
  (Brown, 2008)

2.3.2 Ideation

- Brainstorming
  Make ideas, wild and crazy. Build creative frameworks, order out of chaos.
- Workshop
  Are valuable ideas, assets and expertise hiding inside the company? Invite people with different backgrounds and disciplines. Communicate internally; do not work in the dark.
- Conceptualization
  Process the ideas to concept.
  (Brown, 2008)

2.3.3 Implementation

- Execute the vision
  Engineer the experience
  (Brown, 2008)

This report will discuss the inspiration phase and the ideation phase. The implementation space is out of scope and is left for Volvo CE to consider.
3. Theoretical background

This chapter of the thesis report contains information of the current machines, paver and compactor, and theory about asphalt.

3.1 The paver

The task of the paver is to lay the asphalt on the ground. Information to understand the paver was provided by Anders Rehnström at Customer Center, Volvo Construction Equipment. The asphalt is placed in the hopper by the truck and the asphalt transports backwards in the paver by feeding conveyors. There are usually two feeding conveyers, one placed on the left and one on the right side. The asphalt is transported under the engine and under the driver’s seat and up behind the machine, between the tractor part and the screed. The asphalt is then distributed to the end of the screed by two screws, one at the left and one at the right. The asphalt is then pressed under the screed, where the actual laying of the asphalt takes place, i.e., where the knives and vibratory plates are. The next step is for the asphalt to pass the knives, which can be one or two (single or double-tamper). Screeds with double knives packing the asphalt more than a single tamper, see Figure 2.

When the asphalt transports under the screed plates, it is further smoothed out. Inside the screed, there is also a device with an axis which is unbalanced and thereby causes the entire screed to vibrate as it spins faster. The speed of the axle can be adjusted (more or less vibration), as well as the speed of the knives. Thanks to the knives and vibratory the paver can pack up to 95 % relative density. (Rehnström, 2012)

![Diagram of paver](image)

**Figure 2** Flow chart over the asphalt in the paver.
3.1.1 Volvo paver

The Blaw-Knox paving history started 1929 with the purchase of A W French and Co. French manufactured concrete paving equipment including the paver. Volvo CE concluded the acquisition of US based Ingersoll Rand’s road development equipment division in 2007, (Volvo Construction Equipment). Volvo has two types of pavers, wheeled and tracked.

**Volvo wheeled paver**

New Volvo wheeled pavers offers high traction, maneuverability and flexible paving widths of 2.50 meters to 9.0 meters. The pavers have a powerful and environmentally friendly engine, (Swecon, 2008). The comfort of the drivers is an important part of the machine. The operator of the paver sits safe from the other road users, but it is a noisy and warm work environment. There are a lot of sounds from the truck, the paver and the compactor so the worker normally uses ear protection. Some teams use intercom to communicate with each other, other teams only use their body language.

The wheeled paver is better then the tracked paver if they need to do a shorter transport. That is because the wheeled paver can drive faster.

![Volvo wheeled paver](image_url)

*Figure 3 Volvo wheeled paver*
**Volvo tracked paver**

Volvo tracked pavers are especially suitable for coating many different materials, from the wear layer to the base layer, in the most varied coating mission. The tracked paver is good for medium to large scale projects with the paving widths from 2.5 meter up to 13 meters, (Swecon, 2010). The tracked paver is more flexible to get around on different soils and are gentler to the ground. Apart from that, the tracked paver is similar to the wheeled paver.

![Volvo tracked paver](image)

*Figure 4 Volvo tracked paver*
3.2 The compactor

In 1906, Munktells Mekaniska Verkstad AB made the first steam-powered road roller. Also, Zettelmeyer began as early as 1910 to manufacture steam rollers. The first Volvo branded compactors were launched in the beginning of 2008, (Volvo Construction Equipment).

Compaction has the highest influence on the final quality of the road. The compaction affects almost all the features that influences the coating durability. The better the compaction is, the better durability and resistance to wearing, aging, exhaustion, plastic deformation as well as the effects from rain. Consequently, an inadequate compaction is usually a very bad coating, regardless of wether the mass is assembled and otherwise managed in an impeccable manner. (Zeng H., Bååth, Sjöholm, & Åkesson).

The goal of compacting an asphalt pavement is to achieve an optimum air void content, to provide a smooth riding surface and to increase the load-bearing capacity of the material under construction. (Miller, Huerne, & Dorée, 2007).

The compactor rolls forward over the outlaid mass and presses together the mass, by the pressure of the drums, hence, the coating thickness decreases. The reduction is highest at the first crossings of the drums. A coating of an unpacked condition is for example 36 mm, and after the first two crossings the mass compacts to 34 mm. The change of compression then decreases with the number of passes. The task of the compactor is to compress the entire surface to achieve a sufficient compression of the mass outsourced, see Figure 5. (Zeng H., Bååth, Sjöholm, & Åkesson).

![Figure 5. The compactor presses the asphalt which increases the density of the coating.](image)

The drum can have different characteristics like vibrations and oscillation. The oscillation drum has no vertical amplitude. The drum masses turn in the same direction and produce one moment around the drum axle. The moment changes its effect during a turn in the mass. With this technology the asphalt mass kneads together. (Zeng H., Bååth, Sjöholm, & Åkesson).

The vibration effects by fast rotation make the drum to begin to vibrate, thereby, following compaction forces to arrive into the asphalt. The vibration requires caution because if it is used on to cold asphalt masses, it can crush the mineral aggregate. (Zeng H., Bååth, Sjöholm, & Åkesson).
Besides the number of passes by the compactor there are other important factors to consider with compaction, such as working temperature, outside temperature, layer thickness, material properties and the type of asphalt. Compaction is also affected by variables such as compactor speed, wheel load, compactor frequency and amplitude.

### 3.2.1 Volvo compactor

Volvo has vibrating rollers which are specialized for asphalt compaction in construction from small roads to highways. With the easy to operate electronic control system, they can be maneuvered with sensitivity and precision. Drivers benefit from stable straight ahead travel, uniform cornering and the controlled offset operating mode. Volvo has both compactors with cabin and without, (Swecon, 2008)

![Volvo compactor](image)

Figure 6 Volvo compactor
3.3 Asphalt

Asphalt is the name given to a natural or technically manufactured mixture of the binding agent bitumen and aggregates, which is used in road construction for road surfacing and compaction. Asphalt is a 100 % recyclable material, (GMBH)

Asphalt consists of gravel and the binding agent bitumen, a heavy oil product. Stone and bitumen are heated and mixed in an asphalt mill to asphalt mass. By varying the stone material, size of the stone and binders, you get asphalt with varying properties. In terms of weight (%) asphalt contains about 6 % binding agent, the rest being stone. Converting it to volume units, it will be approximately 14 % binding agent, (Asfaltsteknik).

In order to keep the asphalt soft and easy to work with, it needs to be around 130-160 degrees celsius when it passes the paver.

To get the new asphalt to attach on the soil, especially when there already lays asphalt on the soil, they have to use a substance which works like a glue. The glue consists of bitumen emulsion, it is a levigation of bitumen particles in water. A added emulsifier facilitates the levigation and stops the particles from melting together, (Svensson & Sandahl).

Between five and seven million tons of asphalt per year has produced and distributed in Sweden in the recent years. This represents almost one ton of asphalt per capita per year, which roughly is the average amount in Western Europe, (Asfaltsteknik).
4. Applied solution procedures

This chapter describe how the work has been conducted and which tools and methods have been applied. It also presents parts of the results.

4.1 Inspiration

The first step according to Design thinking is the inspirations phase. The focus has been on learning about asphalt and then taking a closer look at the current machines; pavers and compactors. Furthermore, operators, other road users and ultimately the process of asphalting have been studied.

Volvo’s core values are quality, safety and environmental care. These values have a long tradition and permeate the organization, products and the way of working. All these values are important for me to always have in mind when I am working with this project, (Volvo Construction Equipment).

4.1.1 Collecting information

I have collected information by reading scientific articles and visiting sites. During the site visits I have been given the opportunity to quietly observe the process, as well as to talk to the operators to get their point of view. I have met different teams from different companies, seen different types of work, with different brands of the machines, (Appendix 3-8).

My impression from the site visits is that the working team has a complete overview of each other and their machines. However, the other road users do not have so much control over the work site. My opinion is that they do not show the respect for the workers as they should do. Most of the drivers do not even decrease their speed.

The summary from my site visits is that it takes years of experience to become a good operator of the machines, especially the compactor. Requests from the operators are more comfortable, quiet and with more technical solutions.

A few accidents and incidents with the compactor have happened within the teams I met. At one time the compactor tipped over an edge. On another occasion, the compactor was really close to driving over another worker.
There have also been some minor accidents with the other road users. On a number of occasions, workers have been hit by other cars. Though, this is not verified from statistics, I can still draw some conclusions about the situation. It is a dangerous work environment and there have been some accidents and incidents around the road construction area. Often, the human factor has been the cause.

**Working team**

Today, there is a possibility to be trained as a road worker in high school, but the older generation who works today, is mostly self-taught. The teams consist of one operator of the paver, two to three workers that walk behind the paver and one or more operators who drive the compactors. The operator on the paver takes care of the control and direction of the paver. He also makes sure that there always is asphalt in the hopper. He does so by communicating with the truck drivers who take care of the filling of asphalt in the hopper. Usually they make contact by hand signals to each other.

The operators who walk behind the paver handle the screed, i.e., the height and width of the asphalt. They also do the manual filling and scraping of the asphalt when necessary, e.g., if there would be a hole in the asphalt after the paver or adjust the asphalt edge by scratching it. They also make spot checks with a yardstick, to see if the height really is correct. They use a special solvent that they spray on their shoes and equipment to prevent the asphalt from sticking to it.

According to the operator at Skanska (Appendix 3, 4 and 6), the operator drives the compactor almost only by feeling. Compaction requirement is achieved usually after 4-8 passes, (Zeng, Bååth, Sjöholm, & Åkesson). Though, the reality is very different from what I have been reading. The operators can feel and hear when the asphalt has finished compacting.

**Other road users**

Working with asphalt is a dangerous job, because there are big machines and especially other traffic near the workplace. The separators that they use today to protect the drivers from the operators and vice versa, are pilot cars, flag staff, traffic lights and sergeants, (Appendix 6-8).
The black top process

A very important part of my work has been to identify the process to reach an understanding of the process in order to improve it. I gained a clear view of the process from the site visits. I have used the tool storyboard, see Figure 7, to describe my findings.

![Storyboard over the black top process](image)

**Figure 7 Storyboard over the black top process**

1. The first picture in Figure 7 shows the machine which distributes the glue. The glue is used when paving on existing asphalt, to make it adhere better. The glue consists of bitumen. It is one of the operators who walks behind the paver, which usually run the glue-machine.

2. Early in the day, before the first load of asphalt in the hopper, the feeding conveyers in the hopper need to warm up through electricity or liquefied petroleum gas. The paver stands still for around half an hour to warm up the feeding conveyers.

3. When the paver is ready the truck backs up in the front of paver. The paver pushes the truck forward while the truck is tipping the asphalt in the hopper. The truck slowly tips out the asphalt until it is finished. Then, it
drives away quickly and the next truck immediately comes and begins to tip the asphalt.

Before the work starts, the site manager calculates how much asphalt will be needed and orders it in advance from the asphalt mill. By knowing how much asphalt is required and how far it is to the asphalt mill, it is easy to calculate how many trucks will be needed for the work.

4. The operator of the paver handles the direction of the paver. He can take care of the height and width, though the operators on the ground usually handle that. The driver of the paver has to have good communication with the truck drivers in order to always have enough asphalt in the hopper.

5. The screed is equipped with a vibrator and small knifes so the paver can compact up to 95% of the asphalt.

6. There are usually between 2-3 workers who walk behind the paver. The tasks of the workers are to manually use the tools, shovel and scrape, to correct mistakes from the paver. If there for some reason will be a dip in the asphalt after the paver, the workers on the ground can manually shuffle asphalt in the hollow.

When they are asphaltling next to an already paved road, they sometimes have to scrape the edges a bit, to make them smoother and finer once the compactor comes.

7. The workers behind the paver are usually in charge of the height and width of the new laid asphalt. On both sides of the screed, there are remote controls for this.

8. Asphalt easily gets caught on the worker’s shoes and tools. Therefore they use a solvent spray, that usually contain diesel. (Lundmark, 2012). When they use the spray it allows them to walk on the newly laid asphalt without destroying it.

9. After the paver, the compactor compresses the asphalt even more. The compactor can also have vibrations so the packing can get even better. They usually apply the vibrations on the first overpass. The drum can also has a system that is called oscillation. The oscillation works like a kneading on the asphalt.

The operator of the compactor relies on his perception, he both hears and feels when the asphalt compaction is finished. It is hard to learn that skill, it takes year of experience. They have to be alert as well since it is not good if the asphalt is compressed too much. The gravel in the asphalt can break and later on there could be cracking in the road.
There are different solutions to be found in the market; normally denoted as Intelligent Compaction systems. Volvo is looking at developing such solutions, (Beainy, Commuri, & Zaman). It is an expensive technology, which has not been used at any of the sites I visited. The technology can measure the temperature on the asphalt and also measure how hard compressed, the asphalt is.

10. The compactor can drive in all directions and does not usually drive in any particular pattern. It is particularly important to drive in all directions over the joints, to get them as tight as possible.

11. Approximately 30 minutes after finishing the first compaction of the newly laid asphalt, an additional compaction of the asphalt is done, called cold-compact. This is done to get rid of the traces which can occur when compacting directly after using the paver.

12. The work concludes when the glue machine drives over all the joints. It is important to paste possible joints to bind them together.

For a more detailed view, see Appendix 11.

4.1.2 Structuring information

An important part of the work is to sort all information I have collected. After sorting the data, I could see that what I have read is quite different from the reality.

I have been on six site visits on a radius of 150 kilometers from Eskilstuna. I only saw one team who used a Volvo paver, (Appendix 8). That team was very pleased with the paver, and could not mention one thing they wanted to change on it.

The main reason why I did not find so many Volvo road construction machines is that Volvo has only been in the road construction business for four years and the machines have a long life before replacement. It also takes time to enter the marketing organization and dealer network when new segments are targeted.
4.2 Ideation
This chapter treats the second step in Design thinking, the ideation phase.

4.2.1 Workshops
In the ideation phase I held two workshops, one with students from different programs at Mälardalen University and one with my colleagues from different departments at Volvo CE. They helped me brainstorm about the paver and the compactor and made up concepts for the future machines. Organizing workshops with people from different backgrounds and experience resulted in good workshops.

Anders Wikström at Mälardalen University helped me to plan my workshops for the two groups. I had the same arrangement at both the workshops, see Appendix 12. I started the workshop with a warm-up question; what would you attempt to do if you knew you could not fail? (Dugan, 2012). That question is from an inspirations movie from TED with Regina Dugan. I also showed a short clip of about 3.5 minutes from the movie. After the movie the groups had to answer the question. I asked that question because I wanted them to get in a creative mood and start to think outside the box.

After the warm-up, I taught them the process of asphalting by showing them my storyboard, I also showed some short movies from my site visit in Uppsala, (Appendix 8).

We did a brainstorming on which machine would benefit the most from being automated. I let them make their own storyboard so they could show how the future process would look like. Both groups chose to focus a lot on the paver but they had also solutions for the whole process.

Result from Volvo CE
This is the result from the workshop with my colleagues at Volvo CE:

Figure 8 The future paving process
1. The first picture above show when the truck unloads the asphalt on an autonomous vehicle. The autonomous vehicle is thermally isolated with roof, like a thermos. With the vehicle we can avoid the frustration that can occur when the truck is backing a long way.

2. The autonomous vehicle transports the asphalt to the paver. The difference from before is that the hopper could be maximum filled.

3. Today, a special glue-machine is used. In this solution the paver takes care of that. The operator who drives the paver will have a dashboard so he will take care of everything, the whole paver and the compactors. There will be a scanner which handles the screed. The scanner can feel where the edge is and thereby adjust the screed automatically after the edge.

4. The paver has an ultrasonic indicator which tells the autonomous compactor where it should go. For more information, see Appendix 9.

The Volvo group laid a lot of attention to the whole paving process, from the truck which comes with the asphalt, to the paver with an autonomous screed and to the autonomous compactor. The group had a hard time to just focus on one machine, so I let them go wild and looked at the whole process.

**Results from Mälardalen University**

The students from Mälardalen University did a concretization on their idea. They focused only on the paver, and named their new paver, AST – Asfaltspurttryckaren, see Figure 9.

They wanted to have a truck combined with a paver. The truck will have the screed of the paver in the back, and it will be totally autonomous. The machine will have a laser which shows the way. The AST will pay off in the long run since they do not have to pay salaries. It will also be more effective and environmentally friendly. The machine will be safer when there are fewer machines and workers at the site. For more information, see Appendix 10.

![Figure 9 The AST – future paving machine.](image)
Both groups had very innovative ideas and they helped me a lot to start up a discussion and made me think more open minded.

4.2.2 Selection of machine

Below I have listed my thoughts about both the machines. The lists will help me in my decision on which machine would benefit the most from automation.

The paver:
- The paver is at the forefront in the development.
- The screed can be automatic.
- If the screed will be automatic, the number of operators can be reduced with 2-3 people.
- The customers are pleased with the Volvo paver.
- Volvo CE already has a vision of the future for the paver.
- The paver is not as cost sensitive as the compactor.

The compactor:
- There is significant potential for further development of the compactors.
- There are great opportunities to automate the compactor.
- The customers demand more developed compactors.
- If the compactor will be entirely autonomous, the crew can be reduced with 1 person/compactor.

The customer’s opinions are an important part of this. If the demand does not exist, there is no market for the machine. The Volvo pavers deliver what the customer wants. The operators that I have met on my site visits rather saw opportunities for improvement on the compactor. They want to have it more comfortable and quiet. Some of the operators want a compactor with more technical solutions, like measuring tools for compression.

Considering the many years of practice needed to be a good operator of the compactor and the expensive cost when the work is not satisfactorily performed, some improvement could be beneficial.

After considering the list above, I chose to focus on the compactor. The compactor is in need of improvement. It feels like a real challenge to develop the compactor.
4.2.3 Conceptualization

To make the compactor entirely autonomous, different sensor systems can be the solutions. The compactor must be able to position and identify objects such as other machines and workers.

Sensor systems

Sensor systems are well understood in the different autonomous areas. Below is general information about the different sensor systems I have chosen to work further with.

Radar

“RAdio Detecting And Ranging – or radar – is a method for the detection of distant objects and the determination of their position and velocity. At the most fundamental level, the radar method involves sending radio waves out to a suspected obstacle and timing how long the waves take to return once they are reflected off that object. This allows the determination of distance between source and obstacle. As its name would indicate, the method originally used the radio portion of the electromagnetic spectrum, with wavelengths approximately between 10 and 13 m. As knowledge in the field progressed, the low resolution associated with such large wavelengths motivated a decrease in the wavelength being used, with current radars using wavelengths from as small as 1 mm up to 1 m. This means that most modern radar systems actually use the microwave and very high infrared portions of the electromagnetic spectrum, and the definition has been expanded to accommodate this.” (Radar, 2010)

Radar can be used for measuring distance to other objects. Radar is a well established sensor which is an advantage. It works well for distance measurement and positioning of objects. It is a flexible solution since it only needs a receiver.

The disadvantages with radar are: limited field of view and it can require large equipment.
**GPS**

“The Global Positioning System (GPS) is a network of about 30 satellites orbiting the Earth at an altitude of 20,000 km. The system was originally developed by the US government for military navigation but now anyone with a GPS device, be it a SatNav, mobile phone or handheld GPS unit, can receive the radio signals that the satellites broadcast. Wherever you are on the planet, at least four GPS satellites are ‘visible’ at any time. Each one transmits information about its position and the current time at regular intervals. These signals, travelling at the speed of light, are intercepted by your GPS receiver, which calculates how far away each satellite is based on how long it took for the messages to arrive. Once it has information on how far away at least three satellites are, your GPS receiver can pinpoint your location using a process called trilateration.” (Discover - How does GPS work?)

We can use the GPS for distance- and positions measuring. GPS is available all over the world, all you need is a recipient. But the disadvantages with GPS are that it can give the wrong positions near other machines and buildings, or near hills.

**RFID**

“Radio-frequency identification (RFID) is the use of a wireless non-contact system that uses radio-frequency electromagnetic fields to transfer data from a tag attached to an object, for the purposes of automatic identification and tracking. Some tags require no battery and are powered by the electromagnetic fields used to read them. Others use a local power source and emit radio waves (electromagnetic radiation at radio frequencies). The tag contains electronically stored information which can be read from up to several meters (yards) away.” (Radio-frequency identification)

According to what I have been reading, I think RFID can work if it is possible to equip the paver with tags so that the compactor can get information from the paver. The information it gets can be position. I think it is a good solution to the positioning problem.

There are two types of tags, active and passive. The difference between them is that the active tag has its own battery source. The active tag is better than the passive tag when it has a longer reading distance of up to ten meters. However, you have to remember to change the battery to the tag.

One disadvantage of RFID is that you today can clone a tag, but you can also protect the transmission between two tags and the transponder with cryptography. Tags with this safety function demands more power and on that way they get more expensive to develop. It also requires a large number of tags.
LIDAR

“LIDAR (Light Detection And Ranging, also LADAR) is an optical remote sensing technology that can measure the distance to, or other properties of a target by illuminating the target with light, often using pulses from a laser. LIDAR technology has application in geometrics, archaeology, geography, geology, geomorphology, seismology, forestry, remote sensing and atmospheric physics, as well as in airborne laser swath mapping (ALSM), laser altimetry and LIDAR contour mapping.” (Lidar)

Lidar’s advantage is that the beam has a very narrow beam angle, so the light produces reflections from the particles of the same magnitude as the wave-length of light. You get both the position of length and height.

2D LIDAR scans only in one plan, but we can use them in different angles and the fact that the vehicle moves, can compensate to better and safer readings. However, it can not get the same effect as a 3D.

A disadvantage is that LIDAR has significantly less ability to see in bad weather conditions, like clouds, rain and snow. It also has a sharp laser beam which is harmful for the eye.

Infrared

“Infrared (IR) light is electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 0.74 micrometers (µm) to 300 µm. This range of wavelengths corresponds to a frequency range of approximately 1 to 400 THz, and includes most of the thermal radiation emitted by objects near room temperature. Infrared light is emitted or absorbed by molecules when they change their rotational-vibrational movements.” (Infrared)

The infrared cameras are usually small and flexible to work with. Disadvantage can be that the asphalt will be very warm.
**Stereo Vision**

“Stereopsis (from *stereo-* meaning "solid" or "three-dimensional", and *opsis* meaning appearance or sight) is the impression of depth that is perceived when a scene is viewed with both eyes by someone with normal binocular vision. Binocular viewing of a scene creates two slightly different images of the scene in the two eyes due to the eyes' different positions on the head. These differences, referred to as binocular disparity, provide information that the brain can use to calculate depth in the visual scene, providing a major means of depth perception. The term stereopsis is often used as short hand for 'binocular vision', 'binocular depth perception' or 'stereoscopic depth perception', though strictly speaking, the impression of depth associated with stereopsis can also be obtained under other conditions, such as when an observer views a scene with only one eye while moving.” (Stereopsis)

Stereo vision use two cameras and with the help of triangulation, it can position objects. It is a cheap solution and only requires a small box.

The stereo vision is not able to identify objects, instead you can use vision with a single camera.

**Ultrasonic**

“Ultrasonic sensors (also known as transceivers when they both send and receive) work on a principle similar to radar or sonar which evaluate attributes of a target by interpreting the echoes from radio or sound waves respectively. Ultrasonic sensors generate high frequency sound waves and evaluate the echo which is received back by the sensor. Sensors calculate the time interval between sending the signal and receiving the echo to determine the distance to an object.” (Ultrasonic sensor)

Ultrasonic is a cheap sensor, which is a good advantage. However, ultrasonic does not work so good in city environment because the data usually gets noisy.
5. Results

The material from the site visits, interviews and articles gave me a clear view of the needs of customers. Below I have listed the requirements of the autonomous compactor.

1. The compactor needs to know the distances to different objects in its area and identify objects, like machines and people.

2. The compactor needs to be able to identify people, both moving and stationary, in the range of five meters forward and backward, and one meter on each side.

3. The compactor needs a clear signal when the road piece has finished of compaction.

4. The compactor needs to keep a moderate distance to the paver hence, needs to communicate with the paver.

5. It needs to have a temperature indicator to know when it should do the cold-compaction.

6. Tracking of the road that needs to be compacted and where it has already been, including the number of times a certain area has been compressed.

7. The solutions need to be able to handle the dirty and rough environment around the work sites. The system must be able to handle the vibrations from the compactor.

8. The compactor needs to retain the cabin to facilitate when it is time to load the compactor on a truck for transportation to other works. Alternatively they load the compactor with a remote control.

9. The packing operation is automatically controlled depending on the type of mix of asphalt, thickness and speed.

10. The compactor needs an algorithm, which controls the machine.


### 5.1 Concepts

In order to meet the requirements in the project I have put together concepts with different suggestions on solutions. Together, the following concepts contribute to a complete autonomous compactor.

1. To position machines, workers, other road users and unauthorized person, the compactor can use radar, LIDAR, RFID, GPS, ultrasonic or infrared. The compactor cannot collide with other machines, like the paver or other cars. If there would be a machine in the compactor’s work zone, it will slow down, alternatively, completely stop.

2. To identify people, the compactor can use vision or RFID. The compactor will be able to see if there is an operator or an unauthorized person inside its range. If a worker or unauthorized person is detected inside the compactor’s work zone (five meters forward and backward, and one meter on each side) it will first decrease the speed. Next, completely stop and send a message to the paver that an unauthorized person is in the work zone. It has to be able to see the difference between the qualified workers and unauthorized people.

3. GPS can be used to give the compactor a clear view of where the asphalt is finished of compaction. The operator can decide how many times the compactor should compress. Then the GPS knows where and how many times it had compressed just that spot.

4. To keep a moderate distance to the paver, the compactor can use radar, LIDAR, RFID, GPS or ultrasonic. The workers, who walk behind the paver, will then be able to have enough space and time to do their work. If the compactor gets too close, it will decrease the speed.

5. An infrared sensor can be used as a temperature indicator, so the compactor knows when the asphalt is ready for the cold-compaction.

6. To save information about the number of times the compactor has compressed a specific area, it can be equipped with a small computer. The operators can then print all the important information and have the opportunity to show their clients.

7. To handle the dirty and rough environment, which can be at the work sites, the sensors have to been protected. This could be possible with plastic covers. To handle the vibrations from the compactor, the sensors have to be durable. They all have to be tested in the work environment.
8. So an operator can drive the compactor when it is time to load on a transport machine, the compactor will retain its cabin. The operator must have the opportunity to manually drive the compactor for special cases, such as traffic circles. Alternatively, they load the compactor with a remote control. Another reason to keep the cabin is that the other road users maybe not are ready to meet a driverless compactor on the roads. The compactor will only be autonomous in secluded road construction areas until the general public are ready.

9. After instructions from the operator, it will compress as much as it has been told. The compactor will automatically feel the type of mix and thickness of the asphalt.

10. The algorithm can identify a pattern on the way which the compactor should drive. The compaction will get uniform and result in a better roadway.

Today, the sensor system’s performance is quite limited. However, the technology is believed to exist in the future and I assume unimpaired technology in this report.

Together, all these points contribute to an autonomous compactor with a complete solution. The compactor will deliver what the customer wants.
6. Analysis

The objective of this report was to provide an answer to the following questions:

- How can we increase the effectiveness of production in roadside construction through automation?
- Can this be accomplished while maintaining safety and productivity?

**How can we increase the effective production in roadside construction through automation of a process?**

Through identifying and learning the process, we can see where we can find deficiencies. Today, the operator of the compactor relies on his own perception, he both hears and feels when the asphalt compaction is finished. It is hard to learn those skills and it take years of experience. If we can facilitate that with technology, we save them a lot of time. Moreover, we secure the quality of compaction to the customer.

We can make the compactor completely autonomous through use of sensors. The sensor technologies are still under development. Today, the sensor system’s performance is quite limited. However, the technology is believed to improve in the future and I have assumed unimpaired technology in this report.

**Can this be accomplished while maintaining safety and productivity?**

The safety will be better and the productivity will increase. The compactor can identify people, both moving and stationary, in the range of five meters forward and backward, and one meter on each side. If the compactor detects an unauthorized person, worker or other machine inside its work zone, the first thing the compactor will do is to identify the object. Next, the compactor will decrease the speed. If the object is still there, the compactor will stop completely. Of course, this depends on the speed and distance. If the object is very close from the beginning, the compactor will stop immediately. The compactor will avoid colliding both with humans and other machines, so there will be no accidents. By automation of the compactor the safety will not reduce, instead it will be safer.

The productivity will be maintained, if not even better. The compactor will automatically feel the type of mass and thickness of the asphalt. After instructions from the operator, it will compress as much as it has been told. The compactor can save information about the number of times it has compressed a specific area. It will be equipped with a small computer where this can be possible. The operators can then print all the important information and then have the opportunity to show this to their clients.
7. Conclusions & recommendations

This report has treated how we can increase the effective production in roadside construction through automation of a process. This chapter contains my conclusions and recommendations for further work.

7.1 Conclusions

My assignment was to increase the effectiveness of production in roadside construction through automation. This has been done through collecting information about the workers, the machines and the process. I have identified the process and the needs of customers. The autonomous compactor will be able to measure distance to objects like other machines and people. The compactor will also be able to identify people and machines. It will be equipped with technology which enables to secure the quality of the compaction to the customer. Hence, it provides effective production for the customer. The compactor will offer a complete solution for the purchaser of Volvo.

7.2 Recommendations

After talking to the customers and mapping the paving process, I have obtained knowledge about the wishes and needs of the users. I have acquired a clear view of their spoken and unspoken requirements. The main conclusions are that the compactor needs to be able to position and identify objects and humans. The compactor will work with such precision, so the operators can fully trust it. Volvo is a good brand with loyal purchasers. If Volvo’s compactor matches the customer’s preferences, they will choose them. However, I do not have the experience to ensure that I recommend the best concept.
8. References

*Swecon.* (02 2008). Hämtat från Swecon:
http://www.volvoce.com/SiteCollectionDocuments/VCE/Documents%20
Global/abg%20wheeled/brochureABG5770-
ABG6870_VOE12A1004248_2008-02.pdf den 25 05 2012

*Swecon.* (02 2008). Hämtat från Swecon:
http://www.volvoce.com/SiteCollectionDocuments/VCE/Documents%20
Global/large%20asphalt/brochureDD85-DD95_VOE12A1004433_2008-
02.pdf den 21 05 2012


*Swecon.* (10 2010). Hämtat från Swecon:
http://www.volvoce.com/SiteCollectionDocuments/VCE/Documents%20
Global/abg%20tracked/ProductBrochure_ABG7820B-
ABG8820B_EU_SV_12B1005994_2010-10.pdf den 17 05 2012

*Asfaltsteknik.* (u.d.). Hämtat från Asfaltsskolan:
http://www.asfaltsskolan.se/AllmantomAsfalt.htm den 23 05 2012

Control during the Construction of Hot Mix Asphalt Pavements. *ASCE
Journal of Construction Engineering and Management.*

19, 2012, from IDEO:
http://www.ideo.com/images/uploads/thoughts/IDEO_HBR_Design_Thin-
king.pdf

*Discover - How does GPS work?* (n.d.). Retrieved 05 28, 2012, from Physics -
Your guide to physics on the web: http://www.physics.org/article-
questions.asp?id=55

drone.* Retrieved 05 07, 2012, from TED:
_humming_bird_drone.html

*Gantt Charts.* (n.d.). Retrieved 05 24, 2012, from
http://www.ganttchart.com/index.html

Kaiserslautern, Germany: Fuchs Lubritech GMBH.


*Infrared.* (n.d.). Retrieved 05 30, 2012, from Wikipedia:

*Lidar.* (n.d.). Retrieved 05 28, 2012, from Wikipedia:
http://en.wikipedia.org/wiki/LIDAR

9. Appendices

1. Gantt-chart
2. Requirement specification
3. Site visit: Åkers Styckebruk
4. Site visit: Nyköping
5. Site visit: Eskilstuna
6. Site visit: Katrineholm
7. Site visit: Nacka
8. Site visit: Uppsala
9. Workshop Volvo CE
10. Workshop Mälardalen University
11. Storyboard of the black top process
12. Workshop: idea generation
2. Requirement specification

- Automation of a process in roadside construction.
- Effectiveness
- Identify the asphalt process.
- The new process cannot decrease the safety of the operators.
- The new process cannot decrease the safety of the other road users.
3. Site visit: Åkers Styckebruk 2012-04-18

Summary

- Date: 2012-04-18
- Paver
- Compactor: Hamm, with cabin.
- Access to asphalt, distance = approximately 100 km.
- Number of workers at site: 5
- Skanska
- Security arrangement: none
- Type of job: a big empty area

Description of the work

- I stand at the side of the work and looked, listened and filmed.
- They paved a big empty area at a sawmill in Åkers Styckebruk. They were all alone without any other traffic. The trucks come periodically and the paver where almost never stagnant. Good flow.
- The same worker do the same work every day, the driver of the paver drives it every time and same with the other workers.
- The truck loaded the asphalt in the hopper of the paver and the paver starts to push the truck forward. There where one driver of the compactor, 3 workers who walks behind the paver and one operator who drives the compactor.
- One of the workers who walk behind the paver did random test to see if the thickness of the new asphalt is correct.
- The three workers who walk behind the paver did a lot of work manually with the tools, scrapes and shovel. They have to fix possible mistakes from the paver, like if the paver had missed a spot. Hard work for the body.
- They spray their shoes and tools with a solvent so they could go in the asphalt.
- After the paver, the compactor come and compressed the asphalt. He drives until he thinks he is finished. After 30 minutes he does a cold-compression.
- After the work is finished, one of the workers takes the glue-machine and drive over the asphalt. They do that because they need to seal the joints.
Input from worker

- The driver of the compactor said that it takes time to learn how you should drive, because the things that are said in books do not work in reality.

Reflections

- My first site visits. I did not know much about the process, only the things I have been reading. This was very exciting and I learned a lot!
- Things I have reading about, like the paver cannot stand still during the asphalt process, they did it here. When they are waiting on the truck with the asphalt, they stand still a bit.
- The workers who walk behind the paver walks on the new laid asphalt.
- Good flow and accommodating operators.
- This was their first work for this year.
- The compactor drives close to the workers who walk on the ground.
- The chair in the compactor can change direction, when he drives backwards.
- It was a noisy and warm environment.
- The compressor does not drive in any specially pattern.
4. Site visit: Nyköping

Summary

- Date: 2012-04-19
- Paver
- Compactor: Hamm, with cabin, and one smaller
- Access to asphalt, distance = approximately 3 km.
- Number of workers at site: 5
- Skanska
- Security arrangement: none
- Type of job: a new small road

Description of the work

- They asphalted a new small road. There was no other traffic there.
- It was the same team from Skanska who I met in Åkers Styckebruk.
- They give me the opportunity to drive with the paver.
- They had a smaller compactor this time. They said it was easier to handle that one around the lampposts. They had the bigger Hamm when it was time for straights areas.
- They had a bit difficult at the curves because the truck could not back adjacent to the paver.
- They shoveled a lot manually, where the paver could not reach.

Input from worker

- The driver of the paver told me that he had driven pavers in over 40 years. He did not see any difficulty in the different works.
- He was self-learned.
- The driver of the paver told me that the paver had not developed so much since he starts with this.

Reflections

- Very warm environment
- They covered the brunslock when they asphalted over them.
- They used caps instead of helmet. The caps were equipped with a harder material over the head.
- They use reflective clothing.
- They communicate with each other with body language.
5. Site visit: Eskilstuna, Folkestavägen

Summary

- Date: 2012-04-23
- Paver: Demag DF 115P
- Compactors: One big Hamm with cabin and one smaller.
- Number of workers at site: 5
- NCC
- Security arrangement: none
- Type of job: bicycle road between Brunnsta and Torshälla in Eskilstuna.

Description of the work

- They were asphalting a new bicycle road.
- They were at the bicycle road so they did not need any security arrangement.
- I was on the side and looked at the work, but I also get the opportunity to go with both the paver and the compactor.
- The truck backed adjacent to the paver and start to load the hopper.
- The paver pushed the truck forward.
- There were three workers who walk behind the paver. They had scrapers and shovels.
- After the paver, the compactor come and compressed the asphalt.
- 30 minutes later the compactor drives over the asphalt when it had cooling, a cold-compaction.
- Sometimes when there was no more asphalt in the hopper, they stand still until a new truck had come with asphalt.

Input from worker

- This is one of the easier works they have done.
- The team told me that one time the compactor had tip over an edge, because the groundwork had been bad.
- Another time the compactor has been really close to drive over another worker by mistake, because of the chair which can change direction.
- The driver of the compactor drives on feeling, he hear and feel when the asphalt is finished of compression.
- Would like to have more technology in the compactor.
Reflections

- The operators who walk behind the paver walk on the asphalt.
- They had microphone on their hearing protection so they could communicate with each other.
- They had two meters of grass between them and the other round users.
- The other road users do not slow down the speed.
- The team had work together many years.
- The truck need to backed long distances to get to the paver.
- I get the opportunity to go with the paver. It was warm, noisy and vibrations.
- I also get the opportunity to go with the compactor. He had a cabin with radio and air condition. But still, it was a bit noisy and I could feel the vibrations.
- They had to stop the paver and wait on the compactor, before they could keep asphalting.
6. Site visit: Katrineholm, road 52

Summary

- Date: 2012-05-03
- Paver
- Compactor: Hamm, big one.
- Access to asphalt, distance = approximately 50 km
- Number of workers at site: 5
- Skanska
- Security arrangement: traffic guard and cones
- Type of job: a new bypass

Description of the work

- They had three traffic guards. On different places, but the guards only have one walky-talky to share with each other. The traffic guards had flags to show the traffic if they could drive or not.
- They asphalted a new road, a pass by.
- They took the opportunity to go for lunch when they waited for a new truck with asphalt.
- The compactor drives over the joints.

Input from worker

- They use to have the same drivers of trucks every time they work.
- They did not know about the traffic guard, and they do not like them. The team thinks the guard was in their way and unserious.
- Would more technology in the machines, specially to make the work easier for the workers behind the paver.

Reflections

- It was almost the same team that I met in Åkers Styckebruk and Nyköping.
- There were a lot of other road users and sometimes there were chaos.
- The workers had an exposed work situation with a lot of traffics, like cars and trucks, just around them.
- The working team has full control over each other and their machines. However the other road users do not have so much control over the situation.
- The traffic guards where young men who try to play cool.
- One on the traffic guard had been hit by a car before. He said that the other road users do not like them.
7. Site visit: Nacka, Skvaltansväg

Summary

- Date: 2012-04-26
- Paver, brand, size/type
- Compactor: Hamm
- Access to asphalt (trucks, distance = to understand if that is a limit)
- Number of workers at site: 4
- Skanska
- Security arrangement: concrete stoppers and cones
- Type of job: bus stop

Description of the work

- They asphalted a new bus stop.
- The start the job with the glue machine. They drive the glue were they are going to asphalt.
- They had concrete stoppers and cones to prevent the other road users to hit them.

Input from worker

- The other road users do not show any mercy by slow down the speed. Sometimes they even speed up when they drive pass a working area.
- They had work together in like 8 years.
- This was their first asphalting day, before they had fix with the machines.
- They would like some measuring tools for the compactor.
- Safer working area.

Reflections

- When I arrived to the work, they had just arrived. So we had to wait for the hopper to get warm, it takes about 30 minutes, so we went for food instead.
- I thought it was scary with the other road user so near the workers.
- The other road users did not slow down their speed, it was quite the opposite, the drivers drive even faster. It was unpleasant.
2012-04-26 The paver and the compactor

2012-04-26 The truck with asphalt

2012-04-26 The paver and the other road users.
8. Site visit: Uppsala, Almunge road 282

**Summary**

- Date: 2012-05-04
- Paver: Volvo ABG6870
- Compactors: One Dynapac steel drum roller and one Hamm DV-series
- Number of workers at site: 6
- Skanska
- Security arrangement: light signals and lotsbil
- Type of job: asphalting on an existing road

**Description of the work**

- They were asphalting on an already existing road.
- I stand on the side.
- They use a Volvo paver.
- They use a lotsbil
- They drive two compactors.

**Input from worker**

- One of the workers was from Norway.
- They were very pleased over the Volvo paver. They think it was very quiet and flexible to work with.
- They wanted a safer work area.
- They are pleased with the compactors.

**Reflections**

- They had two big compactors. One was especially good at joints.
- Hamm DV-series with both vibration and oscillation.
- Lot of other road users on the road. They were all following the lotsbil.
- Unpleasant when big trucks were driving by.
- They had to wait for the new truck with asphalt for about 30 minutes. During the time, they were standing still.
The paver and the truck

The compactor

The compactor, the paver and the truck.
9. Workshop Volvo CE
10. Workshop Mälardalen University
11. Storyboard of the black top process
12. Workshop: idea generation

- **Introducing**
  - Short info about the project.
  - What benefits the most by being automated?
  - Starting points: **Effective production**
  - **Safety**

- **Warm-up**
  - What would you attempt to do if you knew you could not fail? (Personal or work-related)
  - They could think about the question while I’m showing a short inspirations movie from TED with Regina Dugan. 3, 35 min
  

- **Information about the process**
  - Show a finished storyboard with the whole asphalt process.
  - Show a short video from one of the site visits. The video showing the whole process from the truck with asphalt to the compactor.

- **Which machine benefits the most by being automated?**
  - Brainstorming about this question in about 10-15 minutes/machine.
  - Then choose the machine with most potential.

- **Storyboard.** The group will do a storyboard with the ideas from the brainstorming. The storyboard will show how the future machine will work.

- **Concretize there idea on the new machine.**