Innovative noise protection solutions for Sweden's first high speed railway

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Abstract

This thesis investigates and design innovative concepts of noise protection solutions (NPS) for the Swedish high-speed railway (HSR) that is planned to be built between Stockholm and Gothenburg in the near future. The planned traffic will start in 2035. The concepts have been developed through a design process, starting with a research phase of existing solutions for the problem, theory about noise and absorbing materials. Following by an analysis of all researched data to narrow down the project and the interviews with the Swedish transport administration, this in order to pinpoint the requirements for the NPS. To get opinions from people who are exposed to low frequency noise, two questionnaires were conducted with a total of 80 respondents. Because of the difficulty to find the exact target group of people who are only exposed to the noise from high speed trains, the first questionnaire was open for all people who are exposed to low frequency noise (traffic noise). The second questionnaire was published at Trafikverket Facebook page, and because of their high number of followers, people who are exposed to train noise could easily be reached. From the answers and the analyzed data, a requirement specification for the NPS was created with all the requirements that the NPS needed to have according to Trafikverkets standards and from the questionnaire. These requirements were the prerequisite used in the synthesis phase. Different brainstorming methods were used to develop a large amount of ideas. A workshop with people from the society was held to keep the creativity alive. From the first synthesis phase, six ideas out of 160 ideas were chosen by a dot evaluation, and in order to narrow down the ideas even more, a matrix evaluation was used. The matrix was built from the requirement specification to verify which ideas fit most of the requirements for a new NPS. From this evaluation, two concepts were chosen to be developed further. After a validation from Trafikverket, the two concepts were further developed, this by an open brainstorming session. Via discussions and sketching, new ideas for the concepts arose. We found solutions for the problems that arose with each concept and made final decisions about the design and material. Three concepts were 3D visualized in the CAD program Rhinoceros. Final touches of the concepts were made in Keyshot. Throughout this thesis, three concepts for noise protections for the HSR have been developed and the research question “How can innovation be created by using a design process?” have been discussed and answered.

Keywords: High-speed railway, noise protection barriers, innovation, design process, NPS
Preface

Thanks to the Swedish Transport Administration; Trafikverket for believing in us and giving us the opportunity to improve Sweden’s infrastructure and work towards a sustainable future.

We would also like to thank our supervisor Lars Löfqvist, for his support and faith in us.
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1. Introduction

In December 2008 the Swedish government assigned a special investigator to examine the conditions in how a high-speed railway (HSR) could be built in Sweden. The report that resulted from the investigation suggested that a HSR should be built between Stockholm - Gothenburg, a distance of 468.5 kilometres. Simultaneously the former Banverket (today, Swedish Transport Administration, in Swedish; Trafikverket) started an inquiry where they put together technical system requirements for HSR in Sweden. These requirements are now the foundation for the ongoing project regarding a HSR between Stockholm and Gothenburg. One part of the HSR project is to develop innovative noise protection solutions (NPS) to reduce the noise that occurs when the train passes by (Trafikverket, 2010).

1.1 Background
Trains have developed in a rapid pace over the last years, however the development on noise protection barriers (NPB) have not kept the same pace. The high-speed trains that will be
trafficking Stockholm - Gothenburg will have a top speed between 250-320 kph. Due to the high speed, the trains will create an aerodynamic noise from the air turbulence around the carriages and the pantograph on top of the engine. Because of its low frequency, this noise is hard to reduce (Trafikverket, 2010). In 2015 an investigation regarding noise from high-speed trains for Swedish conditions were performed. Analysis on measured data and calculations from high-speed trains from Japan, Germany and France were done, where the existing NPB is used. The study presented noise levels 25 meters from the center of the track to be above 95 dB when the train travelled at approximately 300 kph (Persson Waye, 2017). This implies a great challenge to reduce the noise to acceptable levels in location of the railway. To reduce noise on regular railways today, walls or fences are made of wood, glass or gabions, however, these solutions do not reduce the noise level to the accepted highest level for the HSR. This lack of existing solutions on NPB for the HSR points out that there is a need for innovation to gain the needed solutions. The verb “innovation” is used for describing change in products or technological concepts, to innovate is defined as “to introduce changes and new ideas” (Marxt & Hacklin, 2005). According to Norman (2014) incremental innovation refers to changes in a product that improves the performance, lower the cost and increase the desirability or result in a new model. Radical innovation on the other hand is to invent something totally new (Norman, 2014). Innovation can be accomplished by thinking in new ways, to see opportunities for different solutions and finding new ways to work with different material. The design process is a sub process of the innovation process and independent of novelty, innovativeness and experience, a cyclical and experimental design process appears to be suitable (Löfqvist, 2014). With the aim to develop innovative NPS:s suitable for the high speed trains, radical innovation is probably needed via a cyclical and experimental design process.

With the HSR between Sweden's two biggest cities, the Swedish infrastructure will be improved and give people a chance to have a normal workday while they live and work in different parts of Sweden. The high-speed train is estimated to make a few stops along the way, which will give people a possibility to commute to and from these cities. The HSR will create major growth opportunities throughout the regions by reducing the traveling time between the cities. It also gives the residents the option to choose the most environmentally friendly mode of transportation (Chester & Horvath, 2009). Even though trains are the most environment friendly mode of transportation, the noise that the train cause, is a big problem for the residents and their surroundings. Therefore, it is important to keep in mind that the noise from the high-speed trains needs to be reduced in order for people who lives and sojourns adjacent to the railway not will be disturbed about the building of the HSR. The today's NPB are not optimal, the high and solid barriers are blocking the view for drivers and because of the glass barriers are invisible for birds, they tend to fly into the glass barriers if there is not any type of pattern on the glass (Arenas, 2008). Barriers that are made out of planks are too weak to manage the air pressure over a longer time. This makes it important to find functional and innovative designs for a new noise protection that fits everyone in the vicinity of the HSR. To create innovative designs for NPS, an open view to possible solutions is needed, and that can be achieved through a design process. This thesis has used the design process to develop innovative solutions to reduce noise at the HSR.
1.2 Purpose
The purpose with the thesis is to develop innovative product concepts for noise protection solutions (NPS) for the high-speed railway (HSR) with the aim to reduce noise to acceptable noise levels and preserve the environment for people and wildlife that sojourns nearby the railway.

Since this thesis have applied the method of design process to develop innovation, this thesis will also try to answer the research question “How can innovation be created by using a design process?”

1.3 Limitations
Construction, production, life cycle analysis and other complex technical features will not be focused on in this thesis.
2. Theoretical background

2.1 Noise and today's barriers

Today's NPB acts as barriers to sound waves. The barriers work best if there is a large ratio between the dimensions of the barrier and the sound waves. Noise spreads if the sound waves pass over the barriers top without difficulty. The effective NPB height depends on the location of the source of noise in front of the NPB and the receivers’ location behind the NPB. High frequency noise is easier to shield because it is a more direct sound. Low-frequency noise has longer wavelengths and is therefore more difficult to shield. Low frequency noise can pass by NPB unactuated because of the long wavelengths. Train noise has a large spectrum of frequencies and is therefore difficult to shield (Andersson, 1998; Svenska kommunförbundet, 1998).

In order to reduce noise effectively, the NPB needs to be completely tight with no gaps between sections or at the foundation, any openings can destroy the function of the NPB. There are other important factors for the total effect, such as choice of material and the placement in relationship to the railway. The weather can affect the spread of the noise by either damping or amplifying with an affect up to 20-25 dB (Larsson, 1994). There are two types of turbulence, mechanical (wind) and thermal (temperature), which affect the noise extension differently. When phases and amplitude change in sound waves, turbulent propagation occurs. This causes sound waves to interfere with each other and therefore the noise is amplified or weakened (Andersson, 1998).
2.1.1 Guidelines for noise from traffic
The guidelines the Swedish government has determined regarding noise from trains should not exceed certain levels. These levels should be taken into account during substantial rebuilding of infrastructure or new constructions located near a busy road or the railway. Figure 1 shows different noise levels and when people start to be negatively affected by noise (WHO, 1999). According to Prop. 1996/97:53, the guidelines for noise from the railway is 60 dB(A) equivalent outdoors in residential area and the maximum noise level on patio in residential area is 70 dB (A). For reference on noise levels in different environments, World Health Organization (WHO, 1999) has created a table that can be seen in appendix 1.

2.2 Sustainable aspects
Wildlife is affected by noise. Therefore, there is also an ecological dimension to consider (Sveriges kommuner och landsting, 2017). According to Uppenberg et al. (2003) the noise levels are affected by the localizations of the railways as well as how trafficked the railways are. Therefore, considerations on how much the noise will affect the surroundings must be made before reaching a decision on the location of the railway. Recreational values in nature areas are decreased by noise. In areas with high natural and cultural values, the educational value decreases with noise, meaning that people have problems concentrating when there is a high
noise level. In environments with vulnerable species, noise could result in decreasing of the biodiversity if the species are sensitive to disturbance in their surroundings. The levels of noise interference vary with the frequency and the noise source location. Other things that affect the disturbance are the instantaneous level of the noise as well as number of noise disturbance, duration and when it occurs (Uppenberg et al., 2003). According Brunello et al. (2008) and Kuhlman and Farrington (2010) sustainability has more than the environmental dimension, it also spans to economic development and social growth.

Today people who commute between the central Stockholm to central Gothenburg travel mostly by plane because of the distance. The flight time is around 1 hour, however airports is usually not downtown as train stations are. Because of that, the overall travel time (to the airport, flight time and from the airport) when taking a flight between Stockholm and Gothenburg is approximately over 2.5 hours and according to Trafikverket (2018) the high-speed train travel is estimated to be around 2 hours between Stockholm and Gothenburg train stations. Due to the fast travel between these cities, cheaper ticket price for trains and the increasing environmental consciousness among the Swedish population, the high-speed train can outcompete the air traffic between these cities from an environmental and economical point of view and also from a time aspect. Ureña et al. (2009) states that when the travel time is about 1 hour and 45 minutes, 90% of the travelers’ choses to travel by HSR and 10% by airplane. However, when the travel time is >3 hours, >50% of the travelers chooses airplane over HSR. According to Åkerman (2011) implementation of HSR would increase the kilometers traveled by train by 52% calculated to the years 2025/2030 compared to 41% if no HSR were installed. In addition, kilometers traveled by air would decrease from 22% to 11 % if HSR were installed. The HSR will contribute to a long-term sustainable transport system and when the HSR is in use, the capability for freight trains and regional trains on the old tracks will be increased (Åkerman, 2011).

2.3 Strategies for innovation
Innovation plays an important role in an organization’s success. However, innovation does not happen overnight, it is driven by entrepreneurship with a mixture of energy, vision, passion, commitment, judgment and risk-taking (Tidd and Bessant, 2014). Innovation is about creating value from an idea, which requires management and innovative processes. According to Christensen et al. (2015), by being creative and imaginative, with innovation management you can carve out innovation before incumbents. Creativity is not equal to success, however without it, long-term failure is a near certainty (Howard et al., 2008).

Due to global competition, an innovative and creative problem-solving person is rapidly becoming one of the most powerful competitive weapons a company can employ. A company's business ideas consist of continuously delivering solutions to customers' problems and needs. Therefore, you can state that Product development as well as the process that transform ideas into finished products are key parts of a company's business. One of the parts in developing is giving the product a design, this is called the design process. The vision of the design process has changed over time. From being seen as a designer's individual problem-solving process, to be recognized as an integrated work process between multiple participants (Cooper, 1995;
Lundequist, 1995). Furthermore, the view of the design process has gone from linear and sequential to circular and iterative (see figure 2), because of the continuous evaluations made during the process. According to Moultrie, Clarkson and Probert (2007) a design process can be applied in all kind of creative processes.

![Different design processes](image)

**Figure 2. Different design processes.**

There are many models of the design process, the noticeable difference is mainly how structured, stage-based/activity-based and solving-/problem-oriented they are (Clarksson and Eckert, 2005). In addition, there are descriptive (study how) and prescriptive (strict) models on the design process (Clarksson and Eckert, 2005; Cross, 2008). The common thing in the design process, is that the process includes divergence and convergence phases. The divergence phase in the design process is about having the mind wide open in order for all possible solutions and the convergence phase is focused on narrowing down the ideas to one solution and depending if the model is iterative or linear, the phases can accrue more than once. According to Löfqvist (2010), by using the design process, the product department can develop and employees can learn to think in new paths.

Design thinking framework is where the main focus is the human view to strategic innovation and a management model that is working with the human values. This approach is important in a world of radically changing networks and disruptive technologies (Mootee, 2013). Mootee (2013) defines design thinking as the search for the unseen balance between many opposites, i.e. structure and chaos, concept and execution, business and art, intuition and logic. He states that design thinking is all about finding the flexibility and the ability to adapt the process to all the challenges. Introducing design thinking methods in an entire organization requires hard work. Every employee in the company needs to be on the same page and everyone needs to have an understanding of the importance of why the design thinking program has to succeed (Kupp et al., 2017). However, if the process is too strict and formalized it has a negative effect in development in terms of novelty and speed (Kahn et al., 2006).
3. Method

Dynamics is essential for innovation. By using an iterative design process, dynamic is formed. Börjesson and Elmquist (2011) highlights how important it is that everyone in the group is familiar with the design process, to make sure that everyone knows what to do in order to avoid getting stuck in the process because of uncertainty. With the limited time for this project, it was decided that a cyclical, dynamic and experimental design process was most suited for this project. Also, because there was former knowledge about this sort of design process and because this project required processed solutions.

With a dynamic mind-set using design principles, the concepts for the NPS have been created. In order to get as many concepts as possible in a project, the purpose in a project needs to be intentionally diffuse, this to manipulate the mind to visualize different sorts of solutions (Jonassen, 1997). The design process is an approach to break down a project to more manageable parts. The design process is executed differently depending on the problem. Wikberg Nilsson et al. (2015) states that by analysing needs and demands can a definition about what the solution should manage arise without presenting the final solutions. Different projects have different design processes; however, the process is essential in order to find solutions
A cyclical, dynamic and experimental design process have been used in order to develop innovative NPS. Clarkson and Eckert (2005) states that an iterative process is important when innovation is desired. Therefore, the synthesis and evaluation phase have been repeated in this project. A disadvantage with the design process is that it does not guarantee the best solution, especially when the project time is extremely limited. However, by using the design process, problems can be solved in new and creative ways with unpredictable results.

The phenomenological approach in this project gives the opportunity to look behind the details. A phenomenologist does not choose to look at a solution as getting from a to b with a single line but instead looks for solutions in many different ways (Remenyi et al., 1998). This holistic perspective is important to have if innovation is the aim.

Cross (2008) mentions the phases research, analysis, synthesis, evaluation and communication in his book. These phases have in this project been important in order to successfully achieve innovative solutions for a NPS. To manage the project, a Gantt schedule with all the phases divided by time and sequence was conducted, see figure 3 below. This because Gantt schedule has a good interface to define problems and to understand and accept a solution (Wilson, 2003). This schedule is a tool used to get a graphical overview of all the different phases within the project. By using a time- and a task axis, the project can be visualized in a simple and understandable way (Österlin, 2012). A Gantt schedule is an optimal way to follow the design process and not spending too much time on certain phases of the project. All phases do naturally intersect with each other, which mean that the phases have occasionally been ongoing at the same time. Especially the communication phase which have been active during the whole project through dialogues with Trafikverket and the supervisor. In the communication phase, documentation of the whole project in a joint logbook is included.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>PLANNED START</th>
<th>PLANNED LENGTH</th>
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<tbody>
<tr>
<td>Research</td>
<td>13</td>
<td>2</td>
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<tr>
<td>Analysis</td>
<td>14</td>
<td>2</td>
</tr>
<tr>
<td>Synthesis 1</td>
<td>15</td>
<td>2.5</td>
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<tr>
<td>Evaluation</td>
<td>17</td>
<td>1</td>
</tr>
<tr>
<td>Synthesis 2</td>
<td>19</td>
<td>1.5</td>
</tr>
<tr>
<td>Communication</td>
<td>13</td>
<td>10</td>
</tr>
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Figure 3. Gantt- schedule.

This thesis has had a cyclic structure (see figure 4): Research, analysis, synthesis, evaluation, synthesis and communication. Here stands the communication phase only for the final touches and the visualization of the concepts.
The first two phases, research and analysis is the most important phases because the data from these phases sets the foundation of the entire project. Within these phases, greater knowledge about the NPB that are used today and their placement in relation to the noise source have been studied. Moreover, a literature study on the subject and materials have been performed as well. The data collection can be divided into primary and secondary data. Primary data means that the information is obtained directly from respondents. Secondary data are information that other people have collected in other purposes. This mostly through published reports and articles (Jacobsen, 2002). Though this project, both primary and secondary data have been used in the data collection. During the research phase, data and information from people who are exposed to NPB have been collected, this by questionnaires for the target group, interviewing Trafikverket and looking for previous research and development within the subject. The questionnaire was intended for people living near railways with existing NPB. This because the opinions from the actual people who are exposed to NPB were valuable and important in order to generate new and innovative ideas when being in the synthesis phase. With the questionnaire, information about the purpose of the project was included. Formal ethical principles need to be applied when interviewing people. According to Blomkvist & Hallin (2015) when interviewing people and creating questionnaires, it is important to inform about the projects purpose, to get their consent to be mentioned in the project, that the collected material is confidential and that the material is only to be used in the content of this projects purpose. Since the questionnaire was posted in groups at Facebook and on Trafikverkets Facebook page, there was no verification on who actually answered the questionnaire, however the questionnaires were posted after acceptance from the administration of the Facebook groups. Which means that the administrators verified and believed that the group members were the right people to answer our questions. Due to the time limitation, far from everyone could be reached through the questionnaires. However, the 80 different answers were similar to each other. The data from the research phase have been analyzed during the analysis phase. From the analyzed data, a requirement specification was conducted. The requirement specification has made the foundation for the designs for the concepts. The requirement specification has been presented for Trafikverket to ensure and verify that something important was not missing in the requirement specification. If there was more time for the thesis, a more thorough research regarding people's experience of NPB could have been
performed. This would have made the data more reliable. On the other hand, it might not have positively affected the outcome of the thesis, as it is known that too much information and data can risk inhibiting creativity.

In the synthesis phase, concepts have been developed from the findings from the research and analysis phase that made the requirement specification. Different brainstorming methods have been used to generate innovative ideas. In order to maximize the outcome from a brainstorming method, one need to know that there are rules that needs to be followed, such as: no criticism or judgment of your or someone else's ideas, crazy ideas are welcome and strive to develop each other’s ideas because it is about quantity and not quality (Österlin, 2012). This makes people think in new ways while maintaining the ability to think in a rational and structured way, which contributes in the product development process (Dumas, 1994). The methods that were used were brainstorming and brain writing. The main purpose with these methods was to create as many ideas as possible, both by sketching and writing (Wikberg Nilsson et al., 2015). An open workshop was also arranged, were people from the society were invited via advertisement on Facebook. The methods used in the workshop were speed storming and brain drawing. Speed storming is a method that has a rapid paced to generate ideas on different problem areas. This method is an inspiration from speed dating and is a good method to use in the beginning of a brainstorming session. This because it helps to set the right focus on the problems and to get quantity over quality when generate solutions/ideas (Wikberg Nilsson et al., 2015). According to Joyce et al. (2010) is speed storming good to use if one wants to accomplish innovation, because the method helps one to think in a new way, by gathering new perspectives from other people (Wikberg Nilsson et al., 2015). Whether or not the participants have any knowledge about the subject, it is known that speed storming contributes to higher-quality interdisciplinary ideas and therefore a wider scope of ideas can be generated (Joyce et al., 2010). Brain drawing is a method where each one in a group draw one idea on a paper and after an amount of time sends it to the person adjacent, where this person further develops that idea in his/her way (Wikberg Nilsson et al., 2015).

To eliminate and sort out the ideas, a dot evaluation (see figure 9) was carried out. The dot evaluation is a good method when one wants to, in an easy and quick way, choose between a big amount of ideas and to know that everyone in the group got to vote on what they thought could be a good idea (Österlin, 2012). To narrow it down even more, a matrix (see figure 10) was conducted in relation to the requirement specification. A matrix is a method when one writes the ideas next to each other and then goes after the requirements specification while writing down scores between 0-5 on to what extent the ideas meet the requirements (Österlin, 2012). The concepts with the highest points from the matrix were further developed. Trafikverket have acted as an executive discussion partner in order to answer the questions that have aroused under the project and validate regarding whether or not the concepts were producible. The concepts were followed by a second round of brainstorming for further development. To finalize and visualize the concepts, the 3D-program Rhinoceros and the rendering program Keyshot was used. Rhinoceros is a program that helps one visualize a product in a clear way while Keyshot helps one to visualize how it could look in the right environment. To place the concept in the right environment, a railway a few meters from a
A residential area without any NPB in Gävle was photographed. The project was then presented and communicated through a presentation. Throughout the project, there was constant communication with Trafikverket, in the group and with the supervisor.

3.1 Method criticism

If the project was going to be redone, it is a big probability that the same design approach would have been used. Because a cyclical, dynamic and experimental design process can provide innovation due to the repeating of phases. However, depending on what would have been found in the research, the outcome may differ. Such as the knowledge that there are a specifically project group who only focus on fix noise levels on existing buildings or new construction at Trafikverket, and that the group where stationed in Gävle. If this had been known from the beginning, the research phase might have had different content, and because the material from the research phase sets the foundation for the synthesis phase, the way to attack the noise problem may have been different.

The respondents from the questionnaire were totally 80 persons, however, it cannot be verified that the respondents are the exact person in the target group. However, when interviewing people, there is always a risk that the answers are incorrect, it is known that people tend to lie. This means that answers from questionnaires or interviews must always consider the lying factor. Another thing that can emerge with questions, is that the respondent does not fully understand the question, and if the questions are asked in a questionnaire, the questions cannot be extensively explained.

The way to evaluate all of the 160 ideas from the beginning can have been done more formerly, maybe with the people from the workshop to have a wider perspective to the chosen concepts. Also, if everyone has had voted similar to each other, both the eliminated and chosen ideas would have had bigger motives, which would have strengthened the chosen concepts.
4. Implementation

In a sustainable and attractive society, good sound quality is important. Accepted sound levels are one of the essentials for a sustainable urban development (Sveriges kommuner och landsting, 2017). In areas where the risks of interference are imminent, the noise should be reduced to an acceptable level. Both ethical dimensions and social relevance are important factors to have in mind when designing the NPS. Since the NPS have to fit into the society, it is important to interview people living near a busy area, to comprehend what they think about the current NPB appearance and understand how the traffic affects them. This because noise affects people’s quality of life, both socially and environmentally (Seidman & Standring, 2010), which made it important to listen to their viewpoint on the existing NPB. This project started with researching and analyzing (see figure 5) NPB and solutions on how to reduce the noise from places that are high busy areas. This in order to really understand what is good respective bad with each of the solutions for NPB.

Figure 5. The Research and analysis phases.
4.1 Materials
To understand more about the existing NPB, a research of the most used material for NPB was performed. The most usual materials that the existing NPB consists of was: polycarbonate, precast concrete panel, PMMA, glass, wooden timber, metal, vegetal, Plexiglas Soundstop and three glass windows (BPF, 2018; WGE Group, 2015; ZAK Acoustic product manufacturer, 2018; Quietstone, 2018; CSLA|AAPC, 2008; Evonik Industries AG, 2012; Crocker and Kessler, 1982). After that was a research about different types of sound absorption and insulating materials available on the market conducted. Where the outcome were various materials such as; High density expanded Polystyrene (EPS), Wood wool, WAVY Acoustic, Glass wool, Noxudol 3100/3101 (Alpha Coustic - City, 2018; Alperovich, 2018; Materia, 2017; Isover, 2003; Noxudol 3100, 2015; Noxudol 3101, 2015). This research provided a good foundation and helped to get the inspiration from another perspective regarding what material could be a good choice for a new NPS. But also to see how different materials can be formed and used to get the best features of a material.

4.2 Questionnaire one
In order to achieve innovation, it is important to understand what the users think of the current solutions and to have an open communication with the people who are affected by the problem, because they might have insight and useful viewpoints (Hipple, 2001). This to enable that the most important features for the NPS will be met according to the residents living near a high busy area. The new solution will also be designed after what the resident thinks is important for the NPS. In order to get a higher number of respondents, a questionnaire was created regarding accommodation living near a busy area. The questions from this questionnaire are shown below.

NPB by a high busy area:
1. How long and how close do you stay within the busy area?
2. How busy is the area?
   Low traffic
   Normal traffic
   High-traffic
3. Are there any noise protection barriers? If yes, do you hear the noise despite the noise protection barriers?
4. Are you affected by the noise? If yes, how?
5. What do you think of the design of the noise protection barriers you know of?
6. What do you think is important with noise protection barriers?
7. What is good and bad with today's noise protection barriers?
The purpose with these questions was to get an understanding from people who are affected by traffic noise and their opinion on the traditional NPB. One of the questions in the questionnaire was about what they thought about the NPB and to see if they could hear the noises from the traffic despite the NPB. Since the residents living near the busy area, are the ones who sees and are exposed to the NPBs, their inputs are valuable and important. In order to make a requirement specification for the solutions for this project, it was important to find out what the residents wanted the NPB to bring, the most important functions for the NPB, and also to make the respondents point out the good and bad with the NPB. These things were important to determine what a new noise solution really needs to fulfil. But also, to know what the society thinks in general about the appearance of today’s NPB. This type of information is important in the design process, in order to design something that the society considers fits in all kinds of environments. The questionnaires were posted on social media (at Facebook, in groups with some type of connection to traffic noise) to get as many answers as possible under a short period of time and in order to find as many people as possible.

4.2.1 Analysis of data
Most respondents from the first questionnaire answered that they live in a radius of 1 km from a busy area. 88% of the respondents answered that they were living near a high-traffic area, 10% lived near a normal busy area and 2% near a low-traffic area. This means that most respondents could associate to the noise from a busy area and have some knowledge and an opinion about the NPB. This was confirmed with the third question where the purpose was to find out if there were any NPB in the busy area, which 73% out of the 88% that lived near a high-traffic area confirmed that some type of NPB were placed at their area. These people found that these NPB were insufficient because they are not deployed on the entire route where the noise occurs. This means that the noise and vibration from the traffic is not reduced enough. According to the respondents, the noise from the traffic could still be heard at their home and some of the respondents claimed that the noise and vibrations can even be heard on the top floor in the house. According to the respondents, this is because of the dimensions of the NPB and also because of the angle for the sound waves to pass over the whole house. Most respondents are affected by the noise in some way. The long-term noise affects people who spend most of their time near a busy road. Some of the consequences are; feeling more stressed and worried, tired and irritated or have trouble sleeping. Some days the noise is louder, depending on which way the wind is blowing. This leads to a bad outdoor environment for most residents when the wind is blowing straight on the houses.

The respondents also mentioned the importance of the environment around the NPB. Something that can help to prevent the noise from the traffic is to think about how the ground is shaped to minimize noise, for example, using specific asphalt designed to dampen the noise of the cars. Which means that something has been designed that fits into the environment, which a large part of the respondents thought was important. As it is, the design of the NPB is insufficient, they are moderate, do not reduce neither noise nor vibrations, in other words, the solutions must be more efficient. The respondents think they are too low/short to help those living near the busy area. The barriers are undersized at places where the noise is high. The
The design of the barriers is not optimal or functional in all places. The main functions that the respondents want the NPS to have are; to lower the noise level, to fit into all different environments and reduce the perception of the constant noise that affects one's sleep. The most common NPB, the wood fence is not an optimal solution because the fence cannot absorb the noise, some respondents' even states that the slim fences only reflect the noise. The NPBs that are the best one on the market is the ones that dampens a high amount of noise and are extended on a bigger area. These types of NPB also contribute to minimizations of accidents with wildlife. The respondents also mentioned the NPB that are made out of glass is good from a traveling perspective, when they can see something other than a corridor when traveling.

**4.3 Questionnaire two**

To receive responses only from residents living near railways, Trafikverket was asked if they could publish a new and improved version of the questionnaire on their Facebook page. The questions from this questionnaire are shown below.

NPB by railway:
1. How far away from the railway are you located?
   - 50-100 meters
   - 100-200 meters
   - 200-500 meters
   - > 500 meters

2. For how long are you located close by the railway?
   - 1-2 hours
   - 2-5 hours
   - 5-8 hours
   - > 8 hours

3. Approximately, how many trains pass by per hour?
   - 0-3 trains per hour
   - 3-5 trains per hour
   - 5-10 trains per hour
   - > 10 trains per hour

4. Are there noise protection barriers? If yes, do you hear the noise despite the noise protection barriers?

5. Are you affected by the noise? If yes, how?

6. What do you think about the design of the noise protection barriers that you know of?

7. What do you think is important for noise protection barrier?

8. What do you think is good and bad with today's noise protection barriers that you know of?
9. Other comments.

In this questionnaire the questions were developed and reformulated in order eliminate misunderstandings from the questions and also to make it easier for the respondents to answer the questions. In the first question from the first questionnaire, was the question about how far they lived from the busy area, which the respondents needed to fill in themselves. In the new questionnaire the respondents got four different choices to pick from, to minimize the misunderstandings and the time it took to fill in the questionnaire. The same was done with the second and third question, where the third question was: “How many trains pass by per hour?” this question was an extension of the questionnaire, in order to get to know how noticeable the train traffic is for the respondents. And also, to get a better understanding of how often they heard the trains compared to how close they live to the railway, how and if they were affected by the noise. Through this second questionnaire was to see if there was something else that occurred for people living near a railway compared to people living near a busy area.

4.3.1 Analysis of data

In this questionnaire, 50% of the respondents were located 50-100 meter from a railway, 27% answered that they are located 100-200 meter away, 8% located 200-500 meter away and 15% located over 500 meters from a railway. About 73% of those how answered said that they are located near a railway more than 8 hours per day, where 31% said that between 0-3 trains per hours passes by and 23% of the respondents answer 3-5/5-10/ > 10 trains per hour. With this data, could the conclusion be drawn that most of the respondents knew what kind of noise the questionnaire was asking about. Also, that the respondents have some knowledge about NPB. Which were confirmed in the following question, where 69% of the respondents said that there are no NPB to reduce the noise the train brings. Which could be why 80% of them said that they are affected by the noise in some way, either because there are too few NPB or they are not high enough. The respondents in this questionnaire claimed that they have trouble sleeping, difficulty to have a conversation outdoors or if a window is open. The noise is also stress producing, causing concentration difficulties because of the constant noise. In this questionnaire some new information arose, such as that it is freight trains that the residents consider to make the most noise, which was something that did not emerge from Questionnaire one. Regarding today’s NPB, most respondents indicated that they thought that most NPB were hideous and do not work when it comes to counteract the noise from the trains. But there are some NPB that they consider to have a better and more appealing design than others. They are the NPBs that are embankments with vegetation and glass barriers that allow one to see through to the other side, which reduces the feeling of traveling through a corridor from the travellers’ perspective.

The questionnaire gave an insight on what the respondents thinks about the different NPBs that are on the market today. Some respondents also stated that, functions other than reducing noise are also desirable. According to the respondents, the most important function NPB is to dampen the noise but at the same time have an aesthetically pleasing look. The NPS should be a part of the environment and not have a design that is to protruding to its surrounding.
4.4 Requirements in the design process

One of the important needs for the NPS is the need to blend into the different surroundings, with no offensive patterns or forms that can be interpreted in the wrong way by different people of the society. Because the HSR will pass through different municipalities who all have their own guidelines on building permits and how the environment aspects should be handled, the demands on how the NPS appearances differs from one municipality to another. The NPS should be functional and fit in both urban and natural surroundings as well as adapted to the demands. The new innovative NPS should not cause any new or other problems, such as reduced sight for people sojourning near the railway. Vandalism is common on railways, especially graffiti. Every year, it costs United Kingdom more than £3.5 million for removing graffiti on railways (Thompson et al., 2012) and with graffiti vandalism, unauthorized persons will trespass the railway. The loss of revenue and patronage associated with vandalism repair and graffiti removal has also a negative impact on the rail brand (Thompson et al., 2012). Because of this, the design of the NPS needs to prevent trespassers and also not encourages for vandalism.

Based on the response from the questionnaires, the interviews with Trafikverket and our research, a requirement specification could be written. The purpose of the requirement specification was to give us guidelines to focus on the right things in the synthesis phase. The requirement specification also worked as directives in the evaluation phase on the solutions. The requirements are based on research on different NPB solution and the questionnaire about NPB from people who spend most of their time in the vicinity of a busy area. Because of the focus on the design of the NPS, complex technical requirements are not described in the requirement specification. The requirements are:

- To be innovative - Because the existing NPB does not function to reduce enough noise, the new solutions need to be developed and innovative to reduce the noise from the HSR.

- Reduce noise and vibrations from all sources from the high-speed train - Reduce the aerodynamic noise and noise from the pantograph and rail.

- Fit in both urban and natural environments - As have been said before, the HSR will pass through different environments and needs to blend in with all environments and the location of the railway.

- Be able to be placed at bridges, viaduct and in the embankment - for Trafikverket it is important that the solutions can be placed at different locations on the railway.

- Prevent trespassers on the railway - The NPS needs to strive to prevent trespassers on the railway, because trespassers are the most common reason for delays.

- Prevent birds to fly in the barriers - The NPS cannot be hazardous for birds.
- Life span over 40 years - The desired lifetime span for the NPS is over 40 years.

- The solution should be able to be replaced under 6 hours at service window - Due to the service window of 6 hours, the NPS needs to be easy to be replaced.

- Social-, economic and sustainable aspect must be applied - For the design and production of the NPS, social-, economic and environmental aspect must be applied.

- The design shall not extract any negative associations - Patterns or shapes on the NPS should not bring on negative associations.

- Have the travel perspective in mind, make view for the traveler - To make the train journey pleasant, the travelers’ perspective must be kept in mind.

- Exits for every 1 km - the recommended distance from Trafikverket for evacuation, the NPS should enable and allow exits for every 1 km.

- Cannot affect the fixed railway - The NPB cannot affect the fixed railway, meaning that the foundation and technique for the attachment of the NPS must be the same as it is today.

- Reduce the equivalent sound level <55 dB and reduce the maximal sound level <70 dB - According to the guidelines from the Swedish government, the equivalent sound level should be under 55 dB and the maximal sound level under 70 dB.

- Height on embankment 2,5 > 4 meters and height on bridge 0,5 > 2 meters - The height on the NPS can be between 2,5 meters to 4 meters on embankment and 0,5 meters to 2 meters if the NPS are placed on bridges.

4.5 Generating of ideas
After the two questionnaires were analyzed and the requirement specification was written, the synthesis could begin (see figure 6). This phase contained the generating methods brainstorming, brain writing, brain drawing and speed storming. These methods were chosen in order to get as many ideas as possible under a short period of time, ideas that were both realistic and unrealistic. This because even the most unrealistic solution could ultimately be transformed into a valuable idea for a definitive solution, an idea that could be important in order to make the solution innovative (Wikberg Nilsson et al., 2015). At the beginning of this synthesis phase, the generating of ideas was performed separately, to avoid getting influenced by each other’s ideas, and also to gain inspiration from different directions. The methods brainstorming and brain writing were used to get as many ideas as possible but also to not get locked in one way of generating new ideas. In order for us to get an even wider perspective, an open workshop was performed. This to help us think more innovative and also to involve the society with their ideas about how a new NPS could look like.
4.5.1 Workshop
An evening in April an open workshop session of two hours was performed with a small group of 5 people from the society of Gävle. The participants had different backgrounds, one co-worker from Trafikverket, graffiti artists and municipal employees. This broad array of people helped us to get different perspectives. Everyone contributed with suggestions, ideas and conceptualization of how an innovative NPS could be designed. The workshop started with us presenting the HSR, rail noise and the purpose of the project. After the presentation, the whole group discussed the problem to verify that everyone understood the noise problem correctly. To create openness for all ideas, the brainstorming methods; speed storming and brain drawing were used. To get everyone in the right mindset, the first method used was speed storming. This method was repeated three times. Everyone started with choosing a category from the requirement specification of the project and then got 3 minutes to come up with as many ideas as possible within that category. Some of the categories were: be innovative, reduce noise, have the travelers’ perspective in mind etc. This to get the ideas flowing and to understand that there are no wrong answers or ideas for a problem. After 3 minutes, the sketches and ideas were discussed and explained, by doing that the group started to elaborate and develop each other’s ideas and got to see that everyone had both crazy and realistic ideas. Once the speed storming was performed, the brain drawing method could start. When using this method, it is important to have an open mind to visualize a solution/idea of how an innovative NPS could look. A three minutes round was set to draw a solution and after three minutes past, the paper with the ideas was send to the person to the left. When received the new paper of ideas from the others, the task was to further develop the idea and give another perspective of the idea. This was performed in a loop of 4 times and afterwards, there was a discussion about the solutions (see figure 7). After two hours of brainstorming in the group, a great number of new ideas had been generated for innovative NPS.
4.6 Evaluation
After two sessions from the synthesis phase, it was time for the evaluation phase (see figure 8) where all the ideas, that were created in the synthesis phase, were looked at. This in order to evaluate which ideas that were realistic to develop further.

To evaluate the ideas (over 160 different ideas) it was needed to scale down the number of ideas in order to get a better overview of the ideas. To do that, a dot evaluation was performed (see figure 9), where 10 dots were to be distributed on the idea the other one thought had the
best potential to become innovative. This to see what the other one thought of the idea and to get a better overview on what the other one thought of the ideas.

![Figure 9. A selection of all ideas and the dot evaluation.](image)

Out of this dot evaluation was 6 ideas chosen, that had gotten ≥2 dots, these ideas are (see figure 10):

- **Cupola** - A solution that is around the train like a dome but at some places it opened up.
- **Flourish** - An idea that has a translucent barrier with vegetation inside, that is in a self-sufficient ecosystem.
- **Vacuo** - A solution that cancels all the sound and noise thru a vacuum chamber that is inside the barrier.
- **Waterfall** - The Waterfall idea was to pump out water on the barrier which makes it look like a waterfall barrier.
- **Illusion** - With ambiguous sentences, a false perception of the reality is created for the traveler with this solution.
- **Maze** - With different material in the barriers, the sound waves needs to find the way out thru the irregularity.
To get an even smaller amount of ideas and to know if the ideas fit as a NPS, a matrix was conducted (see figure 10 and appendix 2). This to evaluate which ideas that met the requirement specification and if they were innovative and functional. The six ideas were lined up in an x axis against the requirement from the requirement specification in a y axis. Were points between 0-5 were distributed, were 0 equals “do not meet to the requirements” and 5 meant that it met the requirements very well. After all ideas were evaluated with points for each requirement, the total points were counted for each idea (see figure 10 and appendix 2).

![Figure 10. The score in the matrix.](image)

From the matrix, two NPS with highest score were selected to be continued with (see figure 11 and 12), these concepts were presented to Trafikverket under an open discussion about the concepts. The two NPS fulfilled most of the requirements and were the most innovative and possible future concepts to actualize. The NPS was visualized with simple sketches in order for Trafikverket to understand the main function and motives with each NPS.

**Flourish**

This NPS (see figure 11) is a combination of transparent barrier and vegetation, this to make the travel more pleasant for the travelers and train driver. The vegetation is there to prevent birds flying in to the barrier and also to give a natural impression. Because vegetation fits into all kinds of environment, Flourish is a solution that is adaptable to all kinds of environments. By adding vegetation inside the transparent barrier, the wellbeing for people that are surrounded by the barrier will rise. Because being surrounded by vegetation makes people happier (Van Renterghem, 2018). The vegetation is inside the transparent barrier because vegetation does not have significant effect on reducing noise but still gives a peaceful feeling. By placing the vegetation inside the transparent barrier and making the barrier a closed ecosystem it becomes maintenance free (Nelson et al., 2010). The top design of the transparent barrier has an arched shape, that will make the sound waves bounce to the ground.
Vacuo

Sound waves cannot be transmitted in vacuum because sound waves need some type of medium for transportation. The NPS need to have a sound quality suitable for its surrounding, with an acceptable noise level with an identifiable sound (Guski, 1997). Therefore, vacuum should be an excellent technique to use in order to reduce the sound waves and low frequency noise from the HSR. To prevent sound waves from transmitting to the outer membrane that is not in vacuum, it is important that the vacuum chamber of the Vacuo barrier (see figure 12) do not touch more than necessary. On the top, a solar system is placed to utilize the solar energy to provide the railway with light. The function and design of the idea Vacuo was discussed with Dr. Håkan Wilhelm Hugosson, Adjunct Lecturer in Physics at the University of Gävle and Patrik Norqvist, Associate Professor at the Department of Physics at the University of Umeå to validate and ensure that the vacuum concept would work in theory.
4.7 Concept development
Trafikverket validated that the concepts could work as a future NPS and was full of expectations on the development of the concepts. After that confirmation the second synthesis phase could start (see figure 13), were the purpose was to find the best solutions and shapes for the concepts. This was done without other people. By looking at old sketches to estimate if any of the other ideas could be added in the development of the NPS.
To get the ideas flowing, an open brainstorming was performed, the two concepts were discussed and evaluated verbally. The main focus was: What would be the best features for the ideas and could they be merged into one concept? The discussion was about what options each concept had and to find solutions from former ideas from the other brainstorming sessions. While discussing, sketches on new and improved solutions for the concepts was made (see figure 14).

After some missteps and some aha-experiences, final features for three concepts for the NPS were puzzled together. The new concepts had features from the two concepts Flourish and
Vacou but also solutions from other ideas. When the concept was finalized in three different designs, in meaning of aesthetics, material, shape and function the last phase could start (see figure 15). To communicate and visualize the concepts, the NPS was drawn in the 3D program Rhinoceros and then rendered in the program Keyshot.

Figure 15. The final phase.
5. Result

Flourish 1.2: Shapeful - with organic shapes and greenery in a closed ecosystem inside the barrier. Shapeful gives the railway a natural look. The top of the barrier is arched in order to steer the sound waves away from the residents living next to the railway. The solar cells on top of the arched of the barrier, gives energy to the lights underneath the arches that lights up the railway and the greenery. See appendix 3 for measures.

Figure 16. Shapeful from the front.
Figure 17. Shapeful’s arch and lamps.

Figure 18. Shapeful at the railway, daytime.
Figure 19. Shapeful in perspective in the evening.
Vacou 2.1 – (Lightflow) - Lightflow consists of frosted Plexiglas Soundstop on both sides and a vacuum chamber on the inside. The side on the barrier facing the railway has a line on the surface. The line gives the travellers eyes a line to follow when looking out from the train. With small a conductive contact placed at the bottom of the barriers that storage the electricity, the lights in the corner at each barrier section lights up its surrounding at night. See appendix 4 for measures.

Figure 20. Lightflow from the front.
Figure 21. Lightflow’s solar cells and lamps.

Figure 22. Lightflow in the evening.
Figure 23. Lightflow at night, from the residents’ perspective.
Vacou 2.2 (Breakfree) - Breakfree is also a vacuum barrier with a pattern of laminated leaves on the surface to give the barrier a natural look. The barrier is placed inside the H-beam, which makes the barrier secure from any disruptions from the train. Solar cells and lights can be placed in the barriers if desired. See appendix 5 for measures.

Figure 24. Breakfree from the front.

Figure 25. Room for solar cells on the concept Breakfree.
Figure 26. Breakfree in perspective.

Figure 27. Breakfree besides the railway.
6. Analysis and discussion

Different innovative concepts on NPS have been developed by building on the existing NPB as a reference model. The concepts were required to be realistic, yet have potential to be further developed. One particular feature that the NPS needs to have, is the ability to adapt to different surroundings. This because the HSR will pass through several communities that have different guidelines regarding aesthetics. This means that the NPS has to be adjustable to its environment and not destroy the surroundings with disharmony. Therefore, the biggest challenge in this project has been to adopt the NPS in different environments in all the communities where the HSR will be placed. The concepts needed to be easy to maintain, which was an important part for the design. The project focused on the aesthetic when it came to developing innovative concepts as well as the three dimensions of sustainability aspects; ecological, social and economic (Kuhlman & Farrington, 2010), when finding the new solutions. This can be achieved by having solutions that have as little effect on the environment as possible, such as minimal releasing of environmentally hazardous substances into its environment. The solutions also needed to be socially adapted in order to not have a negatively effect on the society. To maintain the NPS under the given time for 6 hours, the NPS must be convenient and easy to replace. The manufacturing of the solutions has also been taken into consideration, since the concepts is aiming to be producible in the future and to not fuzzy. This thesis also discussed the aspects of innovation and society benefit and have been the significant part of the project; to find new solutions that reduces the noise that the high-speed trains bring.
With the light from the solar cells, vacuum chamber and greenery inside the barriers, our solutions are innovative in appearance and by the technique on how to reduce noise. The four windows force the sound waves to bounce between the layers and resulting in reducing the noise remarkably (Crocker and Kessler, 1982). The sound waves cannot be transported in vacuum and therefore most of the noise from the HSR will not be spread on the other side of the barrier. Lab and technique tests must be performed on the concepts to determine how well our barriers meet the Swedish government guidelines for rail traffic noise levels both indoors and outdoors. The problem with birds flying into transparent barriers have been prevented with greenery, lines and leafs that are placed at the surface on the barrier. At nights, lamps powered from solar cells lights up the transparent barrier.

All concepts have taken the travellers perspective in mind, with transparent barriers the traveller can see the environment the train passes by. The concept Lightflow gives the traveller a line to follow when looking out the window, the two other concepts gives the barriers a natural look with the greenery. Maintenance has been taken into consideration when developing the solutions, which was one of the demands with the NPS. The NPS needed to be easy to maintain during the maintenance window of 6 hours at night. Because the barriers have the same foundation as today’s barrier, to replace one section should be possible during the service window. There are no exits integrated in our solutions, however, ladders can be placed at every 1 km (or at any other desirable distance). These ladders can be used as exits in case of evacuation. On the concept Shapeful, another solution has to be formed due to the arched top. The height on the barriers is adaptable and can be scaled-down/up in order to be placed at different locations at the railway.

The sustainable aspects have been taken in consideration under the process. The likelihood for vandalism like graffiti is always worth to consider. The costs for interruption because of trespassers and restoration for vandalism are two big and important details that can be prevented by NPB. The NPS must also preclude illegal actions like vandalism and trespassers. Our NPS meets this requirement, due to the height, transparency and the natural elements inside the barriers. Because of the barriers height on embankment, it will be impossible to climb over (without a ladder) and do graffiti on stationary trains. Since the barriers are transparent and include natural greenery, the barriers hopefully do not encourage people to vandalize/paint graffiti on them, because of the natural vegetation and the light on the barriers. Graffiti artists have also an unspoken rule, to not destroy someone else's art or property. Hopefully, graffiti artists see these NPS as something beautiful and because of the light around the barriers, they do not feel safe to vandalize at night. Which could lead to great savings from removing graffiti from objects at the railway. To make the production and assembly of the barrier more sustainable, easier and cheaper, the individual concepts consist on as few materials as possible. Moreover, the light in the barriers runs on solar cells and the greenery inside the barrier Breakfree are laminated and the barrier Shapeful has a closed ecosystem inside and therefore, the greenery is maintenance free. However, we cannot verify if our solutions meet the requirement of a life cycle for 40 years, this has to be further studied and analyzed by Trafikverket. Nevertheless, it is known that a closed ecosystem can survive for 40 years (Nelson et al., 2010), predicting on the initial planting, the plant needs the sufficient
water and soil to grow for 40 years. By help from the closed ecosystems walls, will the plants grow and get shaped after the wall. Which means that they will not be in need off any maintenance.

Because trains are the most environment friendly mode of transportation (Chester & Horvath, 2009) our solutions will improve the Swedish infrastructure by reducing the noise levels for the surrounding residents to the HSR, which in the future, could lead to that HSR might be built to connect and link other parts of Sweden without any complaints from affected residents. Because the requirement for the NPS is to be 4-meter-high, yet giving view from the train, is two off our solutions in a transparent material in order to not cover the travellers’ perspective from the environment outside the train. A solution which could make the train become an even more popular transportation mode in the future.

Creativity is an important ingredient to achieve innovation, both incremental and radical innovation. When following the design process, by being open for all types of ideas, regardless how crazy they may seem from the beginning, the ability to develop innovation will be amplified. By allowing creativity and imaginatively in the innovation management companies can create innovation before incumbents (Christensen et al., 2015). As the theory says, the design process can be structured in different ways, depending on the problem or situation (Cooper, 1995; Lundequist, 1995). In other words, the designer can construct and tailor the process to achieve the best result for a specific problem. That assures that the design process can be applied under different conditions in all sorts of situations. Because design is one discipline that can impact our lives. That the act of observing, analysing and implementing makes the design phases important activities to solve problems, improve solutions and create innovation, which makes design an important element when innovation is desired. To be able to innovate, an innovative culture and environment must be created, it might not be as easy as people think. You constantly have to be positive to changes and new ideas, no matter how crazy they may seem. The trial-and-error that occurs in an iterative design process gives the designer an opportunity to iteratively improve the solution until satisfaction, nevertheless as in all projects, there has to be a time limitation.

According to Howard et al. (2008) creativity do not mean success, yet creativity determines if the company will fail or succeed in the long-term (Tidd and Bessant, 2014). With the design process you create a creative environment, and in a creative environment, who knows where you might end up? Probably with innovative ideas.

To answer our research question, “How can innovation be created by using design process?” for innovation to be accomplished, an open mind is important, this can be automatically created by using the design process. In this thesis innovation have been created via a cyclical, dynamic and experimental design process. The continuously improvements of the concepts have been adopted through synthesis and evaluations, the final concepts have therefore reached an innovative state. A cyclical, dynamic and experimental design process is therefore to prefer to reach innovative results, because of the repeating of phases, which results in well processed
ideas. Innovation can undoubtedly be created with other methods or strategies than the design process, yet it will most likely contain similarly phases/stages as the design process contain.

In this project, all actions to achieve innovation have been taken in consideration and this by using different methods within the design process that helps one to create innovation. From small elements as people’s opinions about the existing NPB via questionnaires to interviewing Trafikverkets specialists about the essentials. The information gave us the knowledge from those who know and have experience from the existing NPB and also factual requirements from Trafikverket. As Hipple (2001) states; it is important to understand both the problem and the need from the user in order to achieve innovation. By receiving the users’ viewpoint, we gave ourselves a better understanding about the problem with the current NPB, which helped us to think in a new way when creating the concepts. Other methods that had a great impact on this project were the different brainstorming methods. These methods open the mind and makes the brainstorming innovative when generating ideas (Wikberg Nilsson et al., 2015) the methods also helped the workshop group to get in the right mind-set when generating ideas. All ideas from the synthesis phase might not be classed as innovative, however ideas can always be further developed or work as a sub function for the end concept. A sub function that gives the final concept the little extra in order to become innovative. Another method that has helped us to verify how innovative the ideas was, was the matrix. In our matrix, the points 0-5 could be made in order to validate how well the ideas met the requirement specification, were the first requirement was: “To be innovative”. According to Österlin (2012) to evaluate and verify ideas, a matrix is a good method.
7. Conclusion

The goal with the project was to bring new ways of thinking to Trafikverket and raise the standards on how NPB can be designed in all kinds of environments. The research question “How can innovation be created by using a design process?” was answered through this project. We can draw the conclusions that innovation can be created by using the design process, and it can be made by repeating the design process’s phases a few times in an iterative process. However, we believe a time limitation for all projects is a must to finalize a project.

By using the design process, we could generate different innovative concepts for NPS by thinking in new paths. By having a holistic and open mind, the creativity and imaginative was amplified. To generate innovative ideas, the right method can be a boost in order to get the ideas to flow. Other input on the problem can give another perspective of the problem which will help to create innovation.

This project has given a platform for further studies when it comes to knowledge of materials and where they can be used. The solutions have given new ideas and raised the standards on how NPB could be designed in different environments.
8. Further developments

These three concepts will be in need for further developments in order for Trafikverket to use our solutions. In order for our solutions to be manufactured and built, the construction, production and other technical features needs to be further researched in order to make sure if these barriers are as functional in reality as they are in theory. Lab and technical test on each concept needs to be performed in order to verify the technology for the concepts. The best suited greenery for the concept Shapeful needs to researched, as well as right planting technique for the closed ecosystem. Full scale prototypes need to be build and evaluated in order to decide the exact dimensions. Production costs for each solution needs to be calculated as well as a life cycle analysis to fulfil the 40 years’ requirement.
References


Appendix

Appendix 1. Noise levels from WHO (World Health Organization [WHO], 1999)

<table>
<thead>
<tr>
<th>Specific environment</th>
<th>Critical health effect(s)</th>
<th>$L_{Aeq}$ [dB(A)]</th>
<th>Time base [hours]</th>
<th>$L_{Amax}$ fast [dB]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outdoor living area</td>
<td>Serious annoyance, daytime and evening</td>
<td>55</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Moderate annoyance, daytime and evening</td>
<td>50</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td>Dwelling, indoors</td>
<td>Speech intelligibility &amp; moderate annoyance, daytime &amp; evening</td>
<td>35</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td>Inside bedrooms</td>
<td>Sleep disturbance, night-time</td>
<td>30</td>
<td>8</td>
<td>45</td>
</tr>
<tr>
<td>Outside bedrooms</td>
<td>Sleep disturbance, window open (outdoor values)</td>
<td>45</td>
<td>8</td>
<td>60</td>
</tr>
<tr>
<td>School class rooms &amp;</td>
<td>Speech intelligibility, disturbance of information extraction</td>
<td>35</td>
<td>during class</td>
<td>-</td>
</tr>
<tr>
<td>&amp; pre-schools, indoors</td>
<td>message communication</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-school bedrooms, indoor</td>
<td>Sleep disturbance</td>
<td>30</td>
<td>sleeping-time</td>
<td>45</td>
</tr>
<tr>
<td>School, playground outdoor</td>
<td>Annoyance (external source)</td>
<td>55</td>
<td>during play</td>
<td>-</td>
</tr>
<tr>
<td>Hospital, ward rooms, indoors</td>
<td>Sleep disturbance, night-time</td>
<td>30</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>Hospital, treatment rooms, indoors</td>
<td>Sleep disturbance, daytime and evenings</td>
<td>30</td>
<td>16</td>
<td>-</td>
</tr>
<tr>
<td>Industrial, commercial shopping and traffic areas, indoors and outdoors</td>
<td>Hearing impairment</td>
<td>70</td>
<td>24</td>
<td>110</td>
</tr>
<tr>
<td>Ceremonies, festivals and entertainment events</td>
<td>Hearing impairment (patrons:&lt;5 times/year)</td>
<td>100</td>
<td>4</td>
<td>110</td>
</tr>
<tr>
<td>Public addresses, indoors and outdoors</td>
<td>Hearing impairment</td>
<td>85</td>
<td>1</td>
<td>110</td>
</tr>
<tr>
<td>Music and other sounds through headphones/earphones</td>
<td>Hearing impairment (free-field value)</td>
<td>85 #4</td>
<td>1</td>
<td>110</td>
</tr>
<tr>
<td>Impulse sounds from toys, fireworks and firearms</td>
<td>Hearing impairment (adults)</td>
<td>-</td>
<td>-</td>
<td>140 #2</td>
</tr>
<tr>
<td></td>
<td>Hearing impairment (children)</td>
<td>-</td>
<td>-</td>
<td>120 #2</td>
</tr>
<tr>
<td>Outdoors in parkland and conservations areas</td>
<td>Disruption of tranquility</td>
<td>-</td>
<td>-</td>
<td>#3</td>
</tr>
</tbody>
</table>

#1: As low as possible.
#2: Peak sound pressure (not LAF, max) measured 100 mm from the ear.
### Appendix 2. The matrix on the 6 concepts.

<table>
<thead>
<tr>
<th>Functions/Concepts</th>
<th>Cupola</th>
<th>Flourish</th>
<th>Vacuo</th>
<th>Waterfall</th>
<th>Illusion</th>
<th>Maze</th>
</tr>
</thead>
<tbody>
<tr>
<td>To be innovative</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Reduce noise / vibrations</td>
<td>3</td>
<td>4,5</td>
<td>5</td>
<td>3</td>
<td>3,5</td>
<td>4</td>
</tr>
<tr>
<td>Fit urban / natural environments</td>
<td>0</td>
<td>4</td>
<td>2,5</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Bridges, viaduct / embankment</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Prevent trespassers on the railway</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Prevent birds to fly in the barrier</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Life span over 40 years</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Replaced under service window</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Sustainable aspects</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Not extract any negative associations</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>The travel perspective</td>
<td>2</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Exits for every 1 km</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Can not affect the fixed railway</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Reduce the equivalent sound level &lt;55dB</td>
<td>3</td>
<td>4,5</td>
<td>5</td>
<td>3</td>
<td>3,5</td>
<td>4</td>
</tr>
<tr>
<td>Reduce the maximal sound level &lt;70dB</td>
<td>3</td>
<td>4,5</td>
<td>5</td>
<td>3</td>
<td>3,5</td>
<td>4</td>
</tr>
<tr>
<td>Height on embankment 2,5 &gt; 4 meters</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Height on bridge 0,5 &gt; 2 meters</td>
<td>0</td>
<td>5</td>
<td>5</td>
<td>0</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

| Total Sum                                      | 34     | 78,5     | 78,5  | 49        | 74,5     | 69   |
Appendix 3. Shapeful’s measures.
Appendix 4. Lightflow’s measures.
Appendix 5. Breakfree’s measures.