Designing a Vehicle Restraint System for Nordic Conditions

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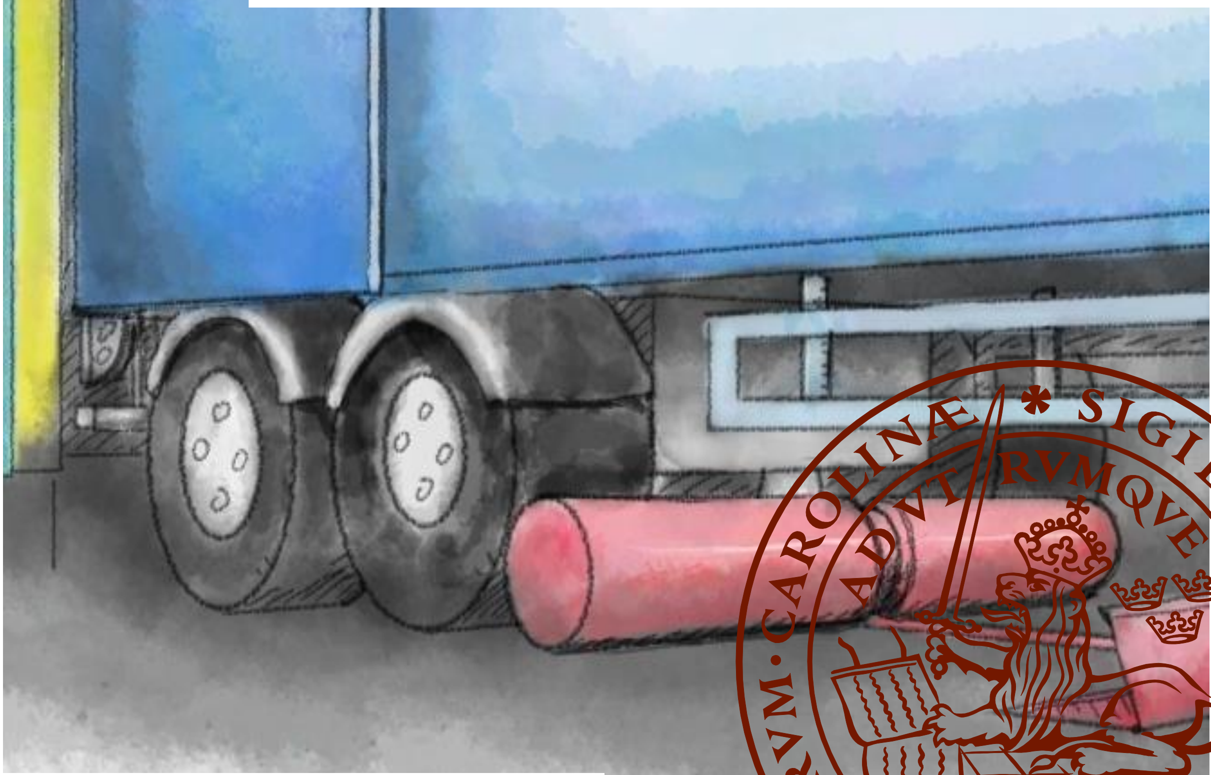
MASTER THESIS



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Designing a Vehicle Restraint System for Nordic Conditions

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Abstract

This thesis explores how to design vehicle restraint systems specifically for Nordic climates. Cargo trucks prematurely departing from loading bays can cause serious damage to goods and personnel. To combat this problem vehicle restraint systems are commonly used to physically keep the trucks in place. However, many of these systems require permanent installations in front of the loading dock, making snow removal difficult. This has led to many facilities in Nordic countries opting out of using restraint systems altogether.

Based on identified requirements, standards, and literature over 100 product ideas were generated and evaluated. Finally, one concept was chosen and further developed. The chosen design was based on an already existing system but modified to allow the whole product to be folded vertically when not in use. This significantly reduced its footprint on the loading ground and enabled the use of snow ploughs.

Further development is recommended to include a more thorough risk assessment, as there are some safety concerns with the current version. However, it is important to note that the concept is in a proof-of-concept stage and that the final design and functionality is subject to change. This thesis aims to lay the groundwork for any further exploration of the product idea and hopes to help increase workplace safety at Nordic logistics centres.

Keywords: vehicle restraint systems, workplace safety, loading bays, cargo trucks, loading and unloading operations

Sammanfattning

Detta examensarbete utforskar hur förankringssystem kan anpassas för nordiska klimat. Lastbilar som oväntat kör i väg från lastkajer kan leda till allvarliga skador på gods och personal. För att motverka detta problem används ofta förankringssystem som fysiskt håller fast lastbilarna. Då många förankringssystem kräver fasta installationer framför lastkajen gör de det omöjligt att använda snöplogar. På grund av detta har många nordiska logistikcenter valt att inte använda sig av något förankringssystem.

Utifrån identifierade kundkrav, standarder och litteratur genererades och utvärderades över 100 produktidéer. Slutligen valdes en av dessa för vidare utveckling. Det valda konceptet var en modifierad version av ett redan existerande system, där uppvikning av hela systemet gjordes möjligt. Detta minskade ytan produkten tog upp på lastkajen avsevärt och möjliggjorde användning av snöplogar.

Framtida utveckling rekommenderas innehålla en mer omfattande riskanalys då det finns risker med det nuvarande konceptet. Det är dock viktigt att notera att den slutversion som presenteras i detta arbete är ett proof-of-concept och kan komma att ändras både design- och funktionsmässigt. Denna rapport syftar till att utgöra en grund för framtida arbete inom området och hoppas kunna bidra till ökad arbetsplatssäkerhet på nordiska logistikcenter.

Nyckelord: lastkajutrustning, arbetsplatssäkerhet, lastkajer, lastbilar, förankringssystem

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Lund, June 2024

Teodor Friberg, Rasmus Kittel

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1 Introduction

1.1 Background and Problem Formulation

Trucks departing from loading bays without proper authorization can cause serious damage to goods and people. To prevent this, a number of products exist that aim to physically restrain the truck from moving until a safe departure is possible. These products vary in both design and effectiveness, but all have one thing in common; they are not suitable for snowy environments.

Assa Abloy is one of the companies active in this market and have identified a need for a more niched product targeting the Nordic market. More specifically they wish to investigate the possibility of developing a restraint system capable of preventing accidental drive-offs while still allowing for snow removal with the use of a snowplough. To accomplish this, they have identified some key needs for the product.

The product should…

- Leave the loading ground clear for sweeping and snow removal.
- Have a robust design with few wear parts.
- Be compatible with European trucks and trailers.
- Have a competitive price point.

1.2 Scope and Purpose

The aim of this project is to investigate how a restraint system specifically tailored for Nordic conditions could function, what it could look like, and what the related needs are. A risk analysis will be conducted to identity potentially hazardous situations.

The proposed solution is to be both physically and digitally modelled and tested through FEM-based simulations. The final concept will then be presented in the form of a set of specifications, a product architecture, and a scaled physical model.

Finally, a recommendation of how to continue development of the project will be presented.

2 Theory

2.1 Introduction to Loading Dock Equipment

2.1.1 **Dock Levelers**

When a truck is parked at a loading dock there is likely a height difference between the truck bed and warehouse floor. This step prevents forklifts from entering the truck and can be a tripping or falling hazard to warehouse workers. To compensate for this gap a *dock leveler* is often used. These work by extending a *lip* into the truck and letting it rest on the truck bed, thus creating a smooth transition between the two surfaces (1).

While many types of dock levelers are available, larger facilities most commonly use hydraulically operated ones (see Figure 2.1). The overall length of the dock leveler is also of interest as it determines the angle of the slope. For industrial applications (use of forklift or pallet trucks) the slope angle is to be $\leq 10\%$ (1).

To ensure a good connection the contact area between lip and truck must be at least 100 mm deep (1).

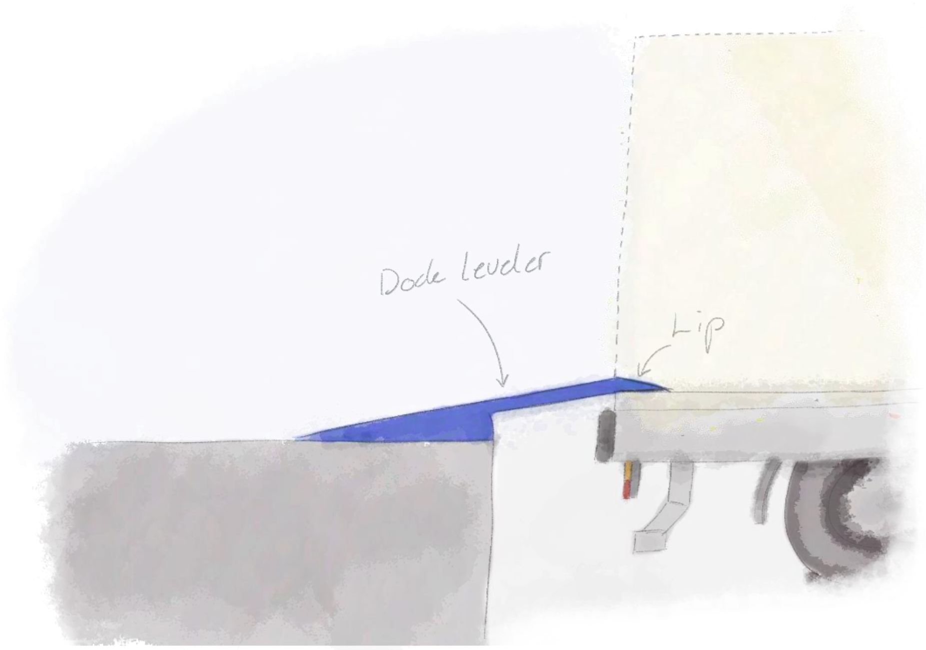


Figure 2.1 Illustration of a dock leveler connected to a truck.

2.1.2 **Vehicle Restraint Systems**

During loading/unloading operations there is a risk of unwanted or unexpected movement of the truck. Whether by wind forces or untimely drive-offs, this could cause the dock leveler lip to slip off the truck bed and create a hazardous gap between the warehouse floor and the truck (2).

To prevent these situations a *vehicle restraint system* can be used. A vehicle restraint system is a device that physically locks the truck in place, aiming to prevent movement and warn workers of the imminent danger (2).

Assa Abloy's automatic restraint system, DE6290AR (henceforth AR), is an example of such a device. This system works by driving a shuttle along a rail, parallel to the truck, until a wheel is detected. A bar is then inserted in front of the wheel and the shuttle reverses to tension the bar against the wheel (see Figure 2.2). To withstand the vertical force of a drive-off the system uses a support leg placed at the end of the bar. When not under load the leg hovers above the ground, and when under load flexes to make contact with the ground. The support leg can be seen in Figure 2.3.

Figure 2.2 Vehicle restraint system DE6290AR in use (3).

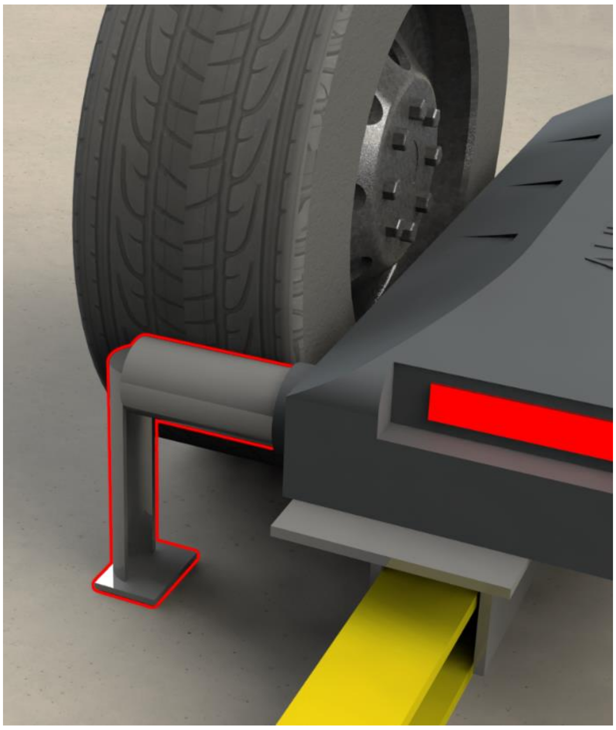


Figure 2.3 DE6290AR support leg.

2.2 FEM Elevating Equipment (FEM 11.005)

To aid in the design and evaluation of restraint systems, a guideline from the European Materials Trade Federation (FEM) is used (2). This guide outlines the purpose of vehicle restraint systems and classifies them according to their maximum restraint force.

It should be noted that while this guide only applies to restraint systems that work by blocking one (or more) of the wheels, the development in this project was not limited to this type of restraint system.

2.2.1 **Restraint Force**

FEM classifies restraint systems according to their maximum restraint force before catastrophic failure occurs (2). The maximum restraint force is calculated as the pullout force when the wheel reaches an equilibrium trying to climb the restraint. This force depends primarily on three factors: wheel size, wheel load, and restraint height. It is calculated using the following formula:

$$Pullout\ force = \frac{Wheel\ load \cdot A}{B}$$

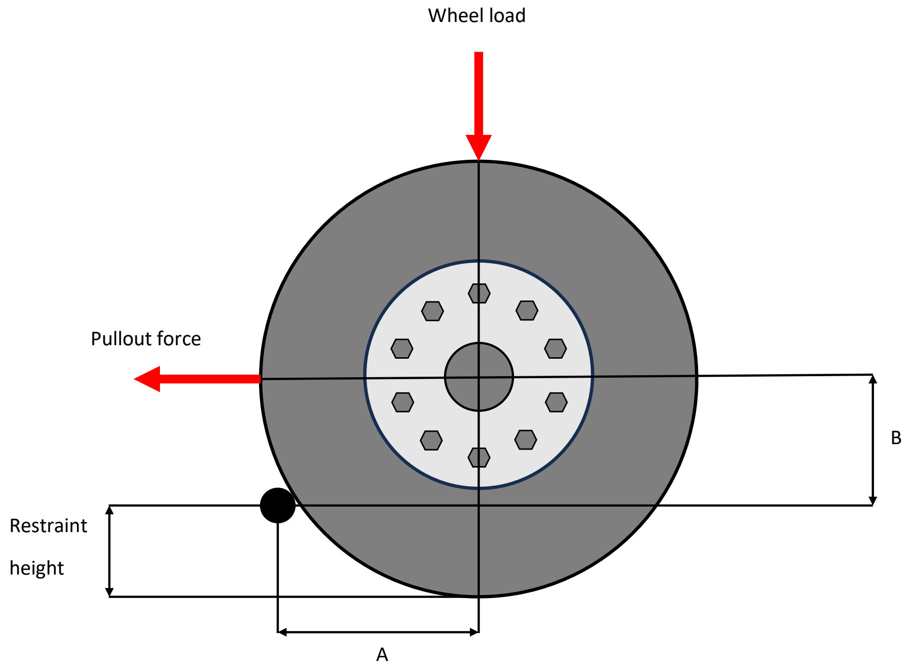


Figure 2.4 Forces acting on a truck wheel using a restraint system.

It is further assumed that the coefficient of friction is ≤ 1, asserting that the pullout force cannot be greater than the wheel load.

2.2.2 **Class 1**

Class 1 restraining devices aim to prevent vehicle *roll-away* (2). Roll-away type situations are typically caused by small forces, such wind friction, and the vertical component of any slope in the driveway. It is estimated that these forces do not exceed 10 kN, giving the upper limit of what a class 1 system is expected to withstand.

2.2.3 **Class 2**

Class 2 systems are built to prevent *vehicle creep* (2). Vehicle creep refers to the cargo truck incrementally "creeping" away from the loading dock due to some repeating force acting upon the vehicle. This force might be caused by a forklift loading or unloading and, in the process, transferring its momentum to the truck.

The force required to prevent vehicle creep, and be classified as a class 2 system, is 35 kN.

2.2.4 **Class 3**

Class 3 devices are designed to prevent unsafe *drive-aways* (2). This means that the truck should be restrained while actively trying to drive off. The systems do, however, not have to prevent the drive-off completely, but rather make it difficult and alert the driver that it is unsafe to depart. To be categorised as a class 3 system the restraint device must be able to withstand a maximum pullout force of 115 kN. This is derived from the maximum allowed driven axel load on public roads. In Sweden, this is stipulated in traffic regulation (1998:1276) (4).

2.2.5 **Safety Factor**

FEM recommends that any restraint system should be designed with a safety factor of 1,5 with regards to the material yield strength (2).

2.3 Safety of Machinery - ISO 12100:2010

ISO 12100 is a standard that provides general information about the safety of machinery and following design principles (5). It also informs of how to identify risks and how to work with risk reduction.

As the final product is used to increase workplace safety, ensuring the safety of the product itself is paramount to the success of the project. The standard is therefore utilised as a guide when conducting the risk analysis in chapter 8.3.

3 Method

This project followed the general process explained by Ulrich and Eppinger in *Product Design and Development* (6) with a few modifications. The Figure below shows how the process was altered to end with a proof-of-concept instead of a development plan. As described further in chapter 4.1.1, the work of gathering and interpreting customer needs was partly done on beforehand by Assa Abloy, leading to less time being allocated to this part. More focus was instead put on concept generation and selection, as well as further development and testing.

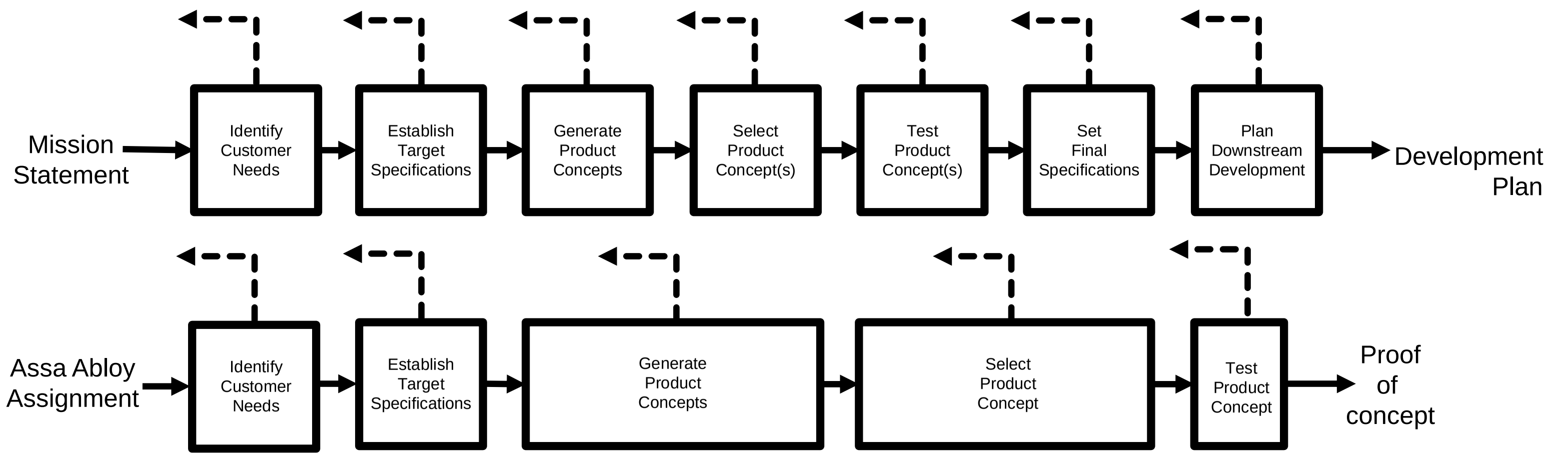


Figure 3.1 The Ulrich and Eppinger process (top) and the modified process (bottom). (6)

4 Identifying Customer Needs

Customer needs can be described as the problems customers have and, in turn, those that the product should aim to address. The identification of customer needs can be a tricky process, but some methods for ensuring good results include interviews, focus groups, and observations of similar products in use (6).

An important distinction between needs and specifications is that needs do not answer the question of how a problem is solved, but rather describes what problem needs to be solved (6).

4.1 Gathering Data

4.1.1 **Data from Assa Abloy**

Some general needs had already been identified by Assa Abloy, as they already had similar products on the market. Also specified were the key changes that would have to be made to make their products more suitable for Nordic conditions. This meant that less time could be spent collecting customer needs, with focus instead directed towards interpreting the provided needs to more specific ones.

4.1.2 **Interviews with Experts**

Some interviews with experts from Assa Abloy were conducted to gain knowledge of design challenges, and to be used to derive needs from. The interviewees were, in this case, not the end customer but rather experts in the field. As the development team had little experience with this type of product these sessions led to a deeper understanding of restraint systems and what goes into their design.

4.1.3 **Stakeholder Identification**

When discussing customer needs it is important to consider who the customer actually is (6). To get a better understanding of the different entities interested in the design and functionality of the product, some stakeholders were identified.

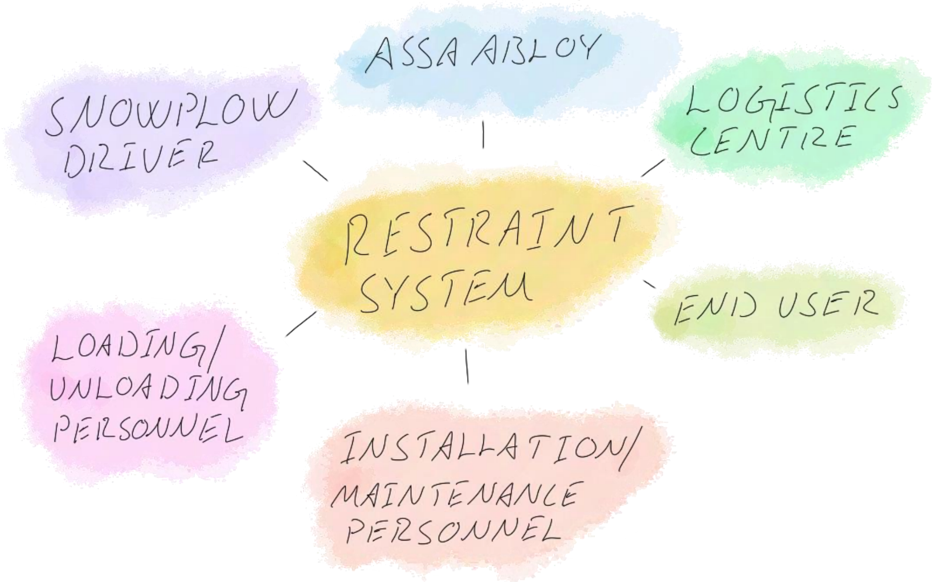


Figure 4.1 Identified stakeholders.

4.2 Interpreting the Data

4.2.1 **Statements to Needs**

The material provided by Assa Abloy and the interviews with experts resulted in what is called *customer statements* (6). Customer statements are often characterised by their unspecific nature. This means that to go from a statement to a specification it is necessary to interpret the meaning behind the statements. The interpreted statements are then listed as *customer needs*. These are used to convey the wishes of the different stakeholders more effectively, and later to derive specifications from.

4.2.2 **Need Hierarchy**

After constructing a list of needs the needs are typically not in any particular order. This can make them difficult to work with, especially if there is a large number of them (6). Some needs might also be closely related to each other, making them prime candidates for group formation. To make it easier to get an overview of the needs the groups are given an umbrella need to serve as a heading for the section. Once grouped the needs are rated based on their perceived importance by the development team.

4.2.3 **Results**

Table 4.1 Customer statements and their respective need interpretations.

Topic	***Customer Statement***	***Interpreted Need(s)***
Most important aspects	The product should focus foremost on the safety of all users involved.	The product is safe to use.
		The product is safe to be around.
		The product is ergonomically designed.
		The product prevents vehicle creep.
		The product stops trucks from driving off.
	It should be convenient to use so that it is actually utilised.	The product can be deployed in few steps.
		The product can be deployed quickly.
		The product can be deployed with low physical effort.
		The product can be returned to its standby position in few steps.
		The product can be returned to its standby position quickly.
		The product can be returned to its standby position with low physical effort.
		The product can be engaged in few steps.
		The product can be engaged quickly.
		The product can be engaged with low physical effort.
		The product can be disengaged in few steps.
		The product can be disengaged quickly.
		The product can be disengaged with low physical effort.

		The product has a standby position close to the docking zone.
		The product is intuitively designed.
	The product should be cost effective and avoid producing unnecessary amounts of scrap metal.	The product is lightweight.
		The product is cheap to produce.
		The product is made of recyclable materials.
		The product allows material separation for recycling.
Specific design requirements	The solution must be tailored to accommodate Nordic conditions.	The product is functional in cold temperatures.
		The product is functional in snowy environments.
		The product is functional in icy conditions.
		The product is functional in wet conditions.
		The product is resistant to corrosion.
		The product is resistant to dust.
	It should leave the loading ground clear for snow removal.	The product is stored away from the loading ground.
	The product has to fit trucks being used in the EU.	The product fits a variety of trucks.
	You should not engage with steering axels.	The product engages with a structurally sound point.
	The design should be robust with few wear parts.	The product is low maintenance.
		The product is impact resistant.
		The product is easy to service.
		The product has a long service life.
Other solutions / competitors	It should be capable of sensing and indicating its state.	The product senses its state.
		The product indicates its state.
		The product can be connected to relevant systems.
	The system should be locked when it would be unsafe to release the truck.	The product is locked in the engaged state while loading/unloading cargo.
	Other solutions are almost always mounted on the driver side of the truck.	The product is easy to line up with.
		The product is tolerant to misalignment.
	Latent needs	The product is easy to install.
		The product can be installed quickly.

	The product can be installed with common tools.
	The product is easy to transport.
Consultation with Assa Abloy expert	The product has a fail-safe system.
	The product locks in place only when engaged correctly.
	The product remains in its current state in the event of a power outage.
	The product has a low stand by energy usage.
	The product has a low engaged energy usage.
	The product is UV-resistant.

Table 4.2 Need hierarchy with grouped and rated needs.

No.	*Importance*	*Need*
1		**The product is a good investment**
2	***	The product has a long service life.
3	**	The product is cheap to produce.
4	**	The product is easy to service.
5	**	The product has a low stand by energy usage.
6	*	The product has a low engaged energy usage.
7	*	The product is low maintenance.
8		**The product is functional in Nordic conditions**
9	***	The product is functional in cold temperatures.
10	***	The product is functional in snowy environments.
11	***	The product is functional in icy conditions.
12	***	The product is resistant to corrosion. (salt)
13	***	The product is resistant to dust.
14	***	The product is impact resistant.
15	**	The product is stored away from the loading ground.
16	**	The product is functional in wet conditions.
17	**	The product is UV resistant.
18		**The product is intuitively designed.**
19	***	The product can be engaged in few steps.
20	***	The product can be deployed in few steps.
21	**	The product can be disengaged in few steps.
22	**	The product can be returned to its standby position in few steps.
23		**The product is recyclable**
24	*	The product is made of recyclable materials.
25	*	The product allows material separation for recycling.

26		**The product is ergonomically designed.**
27	***	The product can be engaged with low physical effort.
28	***	The product can be deployed with low physical effort.
29	**	The product can be disengaged with low physical effort.
30	**	The product can be returned to its standby position with low physical effort.
31		**The product is safe**
32	***	The product is safe to use.
33	***	The product is safe to be around.
34	***	The product senses its state.
35	***	The product indicates its state.
36	***	The product is locked in the engaged state while loading/unloading cargo.
37	***	The product has a fail-safe.
38	***	The product remains in its current state in the event of a power outage.
39	**	The product can be connected to relevant systems.
40	**	The product only allows locking when engaged correctly.
41		**The product is convenient**
42	***	The product can be deployed quickly.
43	***	The product can be engaged quickly.
44	**	The product can be disengaged quickly.
45	**	The product is easy to line up with.
46	*	The product can be returned to its standby position quickly.
47	*	The product has a standby position close to the docking zone.
48	*	The product is tolerant to misalignment.
49		**The product restrains trucks**
50	***	The product prevents vehicle creep.
51	***	The product stops trucks from driving off.
52	***	The product fits a variety of trucks.
53	**	The product engages with a structurally sound point.
54		**The product is easy to install.**
55	*	The product can be installed with common tools.
56	*	The product can be installed quickly.
57		**The product is easy to transport.**
58	*	The product is lightweight.

Note: Primary needs (categories) in bold.

4.3 Reflections on the Customer Needs Identification Process

The gathering of raw data is a step that received little focus in this project, with the reasoning being that Assa Abloy already had identified a gap in the market and the customers' primary needs. The development team were, in this case, not experts in truck restraint systems and had neither experience nor contacts in the field. It was therefore determined that the potential contribution to this step would be small in comparison to what could be hoped for during the rest of the development process. That being said, the needs identified by Assa Abloy were very broad and considerable effort had to be put into interpreting and refining them.

Identifying the stakeholders was a way for the development team to better understand why some needs were important to Assa Abloy, while others were not. It also gave rise to the realisation that the product, however well designed, may not satisfy everyone's needs. Simply because different stakeholders have different wishes. And sometimes they are either not feasible or in direct opposition to one another's. The truck drivers, as an example, seems to be a group that is generally sceptical of using a restraint system. From their perspective it might be seen as additional, and potentially unnecessary, work brought upon them. Listening to only this group one could conclude that having no restraint system would be the optimal solution. However, that is known not to be the case.

When it comes to customer needs, it is also important to note that not all needs are created equal. Some are very broad and some very specific. The main goal when identifying needs is to make sure that all customer statements are represented by one or more needs.

5 Product Specifications

To ensure that the customer needs are taken into consideration during the design process they must first be translated to more well defined statements. The result of this step is called the product specification. The product specification is a list of metrics and values aiming to describe measurable properties of the product and their target values (6).

5.1 Metrics Creation

5.1.1 **Interpretation of Needs**

The process of interpreting the customer needs began with a group discussion where the needs were discussed one by one to determine how to best represent the need with a metric. This method is suggested by Ulrich and Eppinger (6), who also provide some general guidelines for the metrics creation process. The list of metrics should be complete, meaning that every customer need should be fully represented by the metrics. Also emphasised is the need for easily measurable metrics, as they should be a practical tool to use during development. It is further suggested to include common benchmarking properties found in similar products to allow for easy comparison with competing products.

With this advice in mind the list of metrics was created, with each metric given a number, a list of the related needs, the importance of the metric, and the unit of measurement. The importance of a metric was determined by the rated importance its related needs.

5.1.2 **Benchmarking**

Benchmarking was used as a method to compare the product in development with competing products and solutions. In the case of metrics creation, the main use of benchmarking was to understand what similar products were capable of, and to formulate some commonly used metrics. If a metric appeared in relation to more than one competing product it was deemed necessary to be included in the product specification.

Following the method found in *Product Design and Development* (6), it is strongly suggested that in-house testing is done on competing products to get accurate measurements of their performance. However, as the competing products in this case were expensive (often exceeding 10 000 SEK), and due to the time-consuming nature of the process this testing could simply not be justified. Even products from Assa Abloy itself proved difficult to get a hold of as they were mainly produced and sold in France. For this reason, information gathered from publicly available product leaflets and datasheets were used as a basis for the benchmarking data.

5.1.3 **Results**

Table 5.1 Metrics, associated need/needs, importance, and units.

No.	Need No.	Metric	Imp.	Units
1	3	Total production cost	**	SEK
2	7	Mean time between maintenance	***	Months
3	4	Mean time to service	**	Hours
4	2	Warranty period	*	Years
5	5	Standby power consumption	**	Watt
6	6	Max. power consumption	**	Watt
7	15, 32	Protrusion of parts fixed in the ground	***	mm
8	10, 11, 16	Water resistance	***	IPXX
9	9	Operational temperature range	***	°C
10	12, 14	Corrosion resistant	**	Subj.
11	13	Dust resistance	***	IPXX
12	14	Robust design	***	Subj.
13	19	Number of steps to engage	***	No.
14	21	Number of steps to disengage	*	No.
15	20	Number of steps to deploy	***	No.
16	22	Number of steps to return to standby position	*	No.
17	24, 25	Is recyclable	*	Subj.
18	27	Max. force required to engage	***	N
19	29	Max. force required to disengage	**	N
20	28, 30	Max. force required to deploy	***	N
21	32, 33	The Machinery Directive standard	***	Binary
22	35, 39	System compatibility	**	List
23	34	Number of discernible system states	*	No.
24	35	Number of states visually indicated	*	No.
25	36, 40	Prevents unauthorized operation	**	Binary
26	30, 37, 38	Has a fail-safe system	***	Binary
27	42, 47	Avg. time to deploy	***	s
28	46, 47	Avg. time to return to standby pos.	*	s
29	43	Avg. time to engage	***	s
30	44	Avg. time to disengage	**	s

31	45	Acts as a docking guide	*	Binary
32	45, 48	Max. allowed distance from optimal pos.	**	mm
33	45, 48	Max. allowed angle from optimal pos.	**	deg
34	50, 51, 53	Restraint force	***	kN
35	50, 51	Max. allowed creep under load	***	mm
36	52	Min. wheel set diameter	***	mm
37	52	Max. wheel set diameter	***	mm
38	52	Min. dist. to buffer from wheel centre	***	mm
39	52	Max. dist. to buffer from wheel centre	***	mm
40	55	Requires welding to install	*	Binary
41	56	Avg. time to install	**	h
42	58	Total mass	*	kg
43	58	Compatible with EU-pallets	**	Binary

Table 5.2 Benchmarking data following 5.1.2 gathered during the specification creation.

Metric	Units	DE6290AR	DE6190MR	DE6190WC	DE6290TL	TPR Unilock
Total production cost	SEK	68 000	28 000		10 000	
Mean time between scheduled maintenance	Months	4 - 12	4 - 12	4 - 12	4 - 12	3
Mean time to service	Hours					
Warranty period	Years	5	5	5	5	1
Standby power consumption	Watt			~0	~0	~0
Maximum power consumption	Watt	3800	2100	~0	2,4	>36
Protrusion of parts fixed in the ground	mm	535	454	0	0	0
Water resistance	IPXX	IPX5		IPX5		IPX7
Operational temperature range	°C					-40 to 76
Corrosion resistant	Subj.				Painted & galvanized	
Dust resistance	IPXX	IP6X		IP6X		IP6X
Robust design	Subj.	Somewhat	Somewhat	Very	Enough	Very
Number of steps to engage	No.	1	1	1	2	1
Number of steps to disengage	No.	1	1	1	2	1
Number of steps to deploy	No.	0	1	2	2	0

Number of steps to return to standby position	No.	0	1	2	0	0
Is recyclable	Subj.	No	No	No	No	No
Maximum force required to engage	N	0	20	10 - 50	10 - 30	0
Maximum force required to disengage	N	0	20	10 - 50	10 - 30	0
Maximum force required to deploy	N	0	20	10 - 50	<10	0
The Machinery Directive standard	Binary	Yes	No	No	Yes	Equiv.
System compatibility	List	Relevant systems	Relevant systems	Relevant systems	None	Relevant systems
Number of discernible system states	No.	>5	2	2	0	5
Number of states visually indicated	No.	3	2	0	1	5
Prevents unauthorized operation	Binary	Yes	Yes	No	No	Yes
Has a fail-safe system	Binary	Yes	Yes	No	Yes	Yes
Average time to deploy	s	0	5	5	10	0
Average time to return to standby position	s	0	<5	<5	10	0
Average time to engage	s	15	<10	<5	10	>5
Average time to disengage	s	10	<10	<5	10	>5
Acts as a docking guide	Binary	Yes	Yes	No	No	No
Maximum tolerable distance from optimal position	mm	<100	<100	>100	>100	<10
Maximum tolerable angle from optimal position	deg	<5	<5	180	180	<1
Restraint force	kN	200	100	N/A	35	142
Maximum allowed creep under load	mm	<10	100	<10	<10	<10
Minimum wheel set diameter	mm	760	780	<760	N/A	N/A

Maximum wheel set diameter	mm	1200	1150	>1200	N/A	N/A
Min. distance to buffer from the centre of the wheel	mm	985 - 1120	2315 - 2450	0	N/A	N/A
Max. distance to buffer from the centre of the wheel	mm	3865 - 3995	3780 - 3915	8000	N/A	N/A
Requires welding	Binary	No	No	No	No	Yes
Average time to install	h	4	4	1	1	>4
Total mass	kg	800	180	>10	>25	50
Compatible with EPAL EURO PALLET	Binary	No	Yes	Yes	Yes	Yes

DE6290AR data were gathered from the product datasheet (3) and ASSA internal sources and the patent (7).

DE6190MR data were gathered from the product datasheet (8) and ASSA internal sources.

DE6190WC data were gathered from the product patent (9) and ASSA internal sources.

DE6290TL data were gathered from the product datasheet (10) and ASSA internal sources and the patent (11).

TPR Unilock data were gathered from the owner’s/User’s Manual (12).

5.2 Specification

5.2.1 **Defining Ideal and Marginal Values**

After creating the list of metrics some performance values had to be determined. The acceptable values were represented by a range, spanning from marginal values (worst) to ideal ones (best). This span of acceptable values helped the design team by acting as a guideline for the coming steps of the development process.

The marginal values were based mostly on the values of competitive solutions, as to remain competitive in the market. Though some were derived from safety requirements or standards, such as requiring < 100 mm of dock leveler lip contact (1).

The ideal values were set to represent the best possible, but still somewhat realistic, outcome. It is important to note that while ideal values represent a best-case scenario, they are not mean to be interpreted as a target value.

The complete competitor benchmarking table can be found above in Table 5.2.

5.2.2 **Resulting Specification**

Table 5.3 Product specification table with marginal and ideal values.

No.	Metric	Units	Marginal Value	Ideal Value
1	Total production cost	SEK	60 000	10 000
2	Mean time between maintenance	Months	4	12
3	Mean time to service	Hours		
4	Warranty period	Years	5	5
5	Standby power consumption	Watt	5	0
6	Max. power consumption	Watt	3800	0
7	Protrusion of parts fixed in the ground	mm	8	0
8	Water resistance	IPXX	IPX5	IPX7
9	Operational temperature range	℃	-20 to 55	-30 to 55
10	Corrosion resistant	Subj.	HDG [a]	Stainless
11	Dust resistance	IPXX	IP6X	IP6X
12	Robust design	Subj.	Yes	Yes
13	Number of steps to engage	No.	2	0
14	Number of steps to disengage	No.	2	0
15	Number of steps to deploy	No.	2	0
16	Number of steps to return to standby position	No.	2	0
17	Is recyclable	Subj.	No	Yes
18	Max. force required to engage	N	25	0
19	Max. force required to disengage	N	25	0
20	Max. force required to deploy	N	25	0
21	The Machinery Directive standard	Binary	Yes	Yes
22	System compatibility	List	Basic	Relevant Sys.
23	Number of sensible system states	No.	2	3
24	Number of states visually indicated	No.	2	3
25	Prevents unauthorized operation	Binary	No	Yes
26	Has a fail-safe system	Binary	Yes	Yes
27	Avg. time to deploy	s	5	0
28	Avg. time to return to standby pos.	s	10	0
29	Avg. time to engage	s	5	>5
30	Avg. time to disengage	s	5	>5
31	Acts as a docking guide	Binary	No	Yes
32	Max. allowed distance from optimal pos.	mm	50	>100
33	Max. allowed angle from optimal pos.	deg	<1	<5
34	Restraint force	kN	115	>115

35	Max. allowed creep under load	mm	50	<10
36	Min. wheel set diameter	mm	760	N/A
37	Max. wheel set diameter	mm	1200	N/A
38	Min. dist. to buffer from wheel centre	mm	1000	N/A
39	Max. dist. to buffer from wheel centre	mm	4000	N/A
40	Requires welding to install	Binary	No	No
41	Avg. time to install	h	4	<4
42	Total mass	kg	1500	50
43	Compatible with Epal Euro Pallet	Binary	No	Yes

[a] HDG = hot-dip galvanization.

Total production cost was determined during a meeting with the product owner of docking equipment at Assa Abloy where the marginal value was set equal to the rough production cost of their flagship system and the ideal to the production cost of one of their less expensive options.

Mean time to service was, during discussions with experts at Assa Abloy, an important factor for logistics centres. No actual values were able to be defined but the main takeaway from Assa Abloy was that lower is always better.

Protrusion of parts fixed in the ground got its marginal value from the European Agency for Safety and Health at Work (EU-OSHA) who say any change in floor level of 8 mm or more can potentially be a tripping hazard (13).

Operational temperature range was set equal to that of current Assa Abloy products which use electrical motors in northern conditions.

As *corrosion resistance* is difficult to evaluate objectively it was decided to follow the advice of the standards and liability engineer at Assa Abloy who recommended making exposed components of either a hot-dip galvanised material or, optimally, stainless steel.

The *restraint force* was set to achieve a class 3 rating from FEM (see 2.2.4).

Max. allowed creep under load was determined by using a combination of FEM (2), where a lip length of less than 100 mm is determined to be unsafe, and the lip length of Assa Abloy's dock leveler DL6220T of 345 mm (14).

The *Requires welding* specification is mainly derived from the fact that Assa Abloy want to minimize installation time and that welding is a form of hot work. Hot work requires a long period of supervision time after done to prevent any risk of fire (15).

The *total mass of the product* cannot exceed 1500 kg as to remain compatible with an *Epal Euro Pallet* (16).

5.3 Reflections on the Product Specification Creation Process

As this project is an investigation into a new product, the metrics and their values are an important part in defining a potential solution. At the same time, it is challenging to predict which metrics are needed and which are not. The result of trying to create a specification for an unknown solution is a vague and broad list which will need to be updated and narrowed down later down the line when more concrete design decisions has been made. This showed up most clearly when defining some ideal and marginal values in the specification. Specifically, the wheel adjacent values in Table 5.3. Numbers are clearly defined for the marginal values, but N/A (not applicable) is stated for the ideal. The reason being that, ideally, the solution is functional regardless of the size of the wheels.

During the translation process from needs to metrics, the results of which can be seen in Table 5.1, the need to be impact resistant was translated to the product having a robust design. This turned out to be a bothersome metrics that proved itself difficult to define and test. However, it seemed that there was just no good way of translating the need. After consultation with the university supervisor, it was decided to leave the metric as a subjective judgement where it should be taken into account during the design process.

6 Concept Generation

The goal of the concept generation phase was to produce as many different product ideas as possible. All ideas, whether perceived as good or bad, should be included – leave no stone unturned (6). The exhaustive nature of the concept generation aimed to make sure that all possible solutions were considered and, in turn, that the later concept selection would result in the optimal solution.

6.1 Brainstorming

6.1.1 **Broad Concept Generation**

The initial brainstorming session involved asking the question of how to prevent a truck from driving off, and following the guidelines laid out by Ulrich and Eppinger (6). These guidelines are as follows:

1. Suspend judgment.
2. Generate a lot of ideas.
3. Welcome ideas that may seem infeasible.
4. Make plenty of sketches.

All concepts that were generated contained a descriptive name (mostly in Swedish), a unique number, and one or more simple sketches. The goal being to communicate internally in the group and to improve efficiency by reducing the likelihood of duplicates being created in later sessions.

Brainstorming sessions were held on several occasions, generating, and improving ideas using methods like the *wish and wonder* technique from Ulrich and Eppinger (6).

To improve the quality of the concepts and to introduce external stimulation, it was encouraged to generate concepts outside of the group environment (6). To accommodate this, some sessions were set aside for individual concept generation.

6.1.2 **Consulting Experts**

Part of the concept generation process involved searching through external sources for inspiration and information. This to increase the likelihood that all plausible concepts would be explored (6). One way this was done was by consulting engineers and experts in the field at Assa Abloy. One-hour meetings were held where the experts, after a short introduction, were prompted to explain how they would solve the problem. The team also asked questions about obstacles and avenues of engagement to get more general guides. To maximize the effectiveness of the meetings, the team actively tried to continue conversations based on the answers given.

6.1.3 **Competitors and Patents**

Inspiration for product concepts was taken from competitors' solutions. Sources include technical documents, user manuals, videos showing the products in action, and any patents that could be found. As the gathering of inspiration for concepts is a quick process that requires little effort, the list of competitors and other applicable products was expanded from the benchmarking list.

6.1.4 **Concept Tree**

A concept classification tree was used to organize and focus ideation more efficiently. The concept tree was created using the unsorted list of concepts, grouping concepts together based on their working mechanisms and connecting them back to the root problem. The resulting structure was then used as a visual tool, showing where new categories and ideas could be created.

Table 6.1 Concept tree

<table>
<tr><td rowspan="13">Prevent Drive-away</td><td rowspan="3">Moment (torque)</td><td rowspan="2">Locking</td><td>Wheel</td></tr>
<tr><td>Drive shaft</td></tr>
<tr><td colspan="2">Unlocking</td></tr>
<tr><td rowspan="3">Blocking (Compression)</td><td colspan="2">Wheels</td></tr>
<tr><td colspan="2">Front</td></tr>
<tr><td colspan="2">Undercarriage</td></tr>
<tr><td rowspan="6">Holding (tension)</td><td colspan="2">Wheels</td></tr>
<tr><td colspan="2">Rear</td></tr>
<tr><td colspan="2">Front</td></tr>
<tr><td colspan="2">Undercarriage</td></tr>
<tr><td colspan="2">Roof</td></tr>
<tr><td colspan="2">Sides</td></tr>
<tr><td>Abstract/partial</td><td colspan="2">Movement of mechanism</td></tr>
</table>

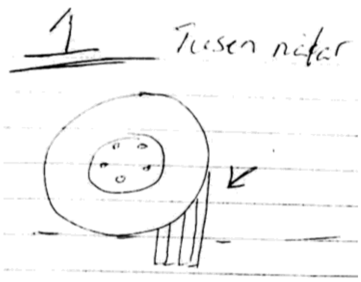
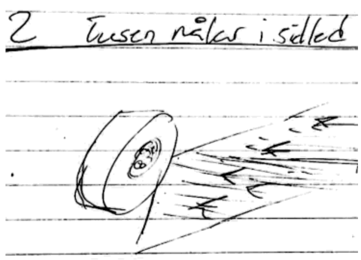
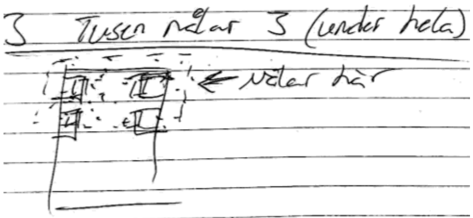
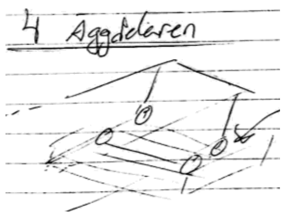
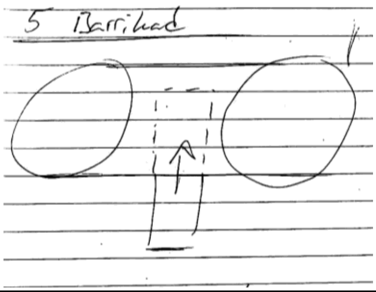
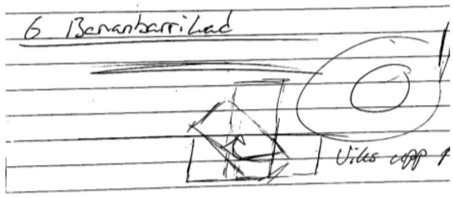
		Outside of the box	Small scale
			Large scale
		Locating	
		Vertical forces	

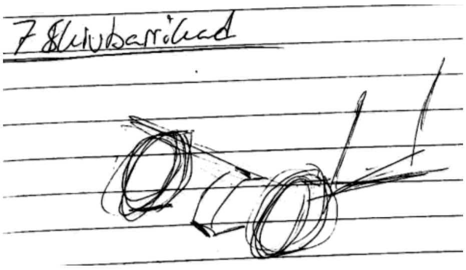
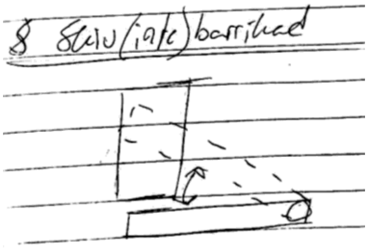
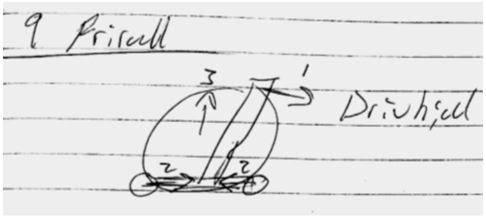
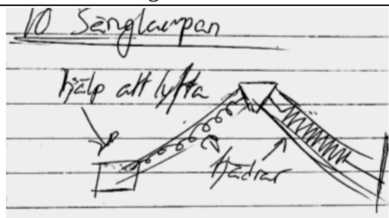
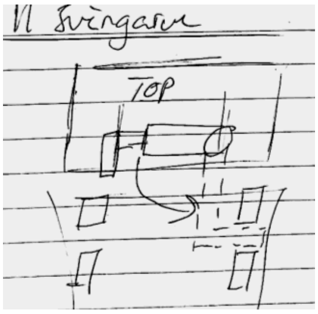
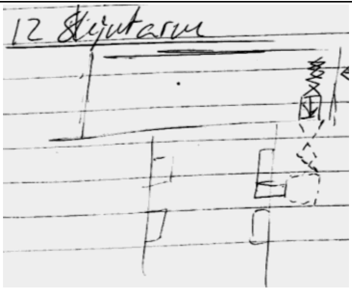
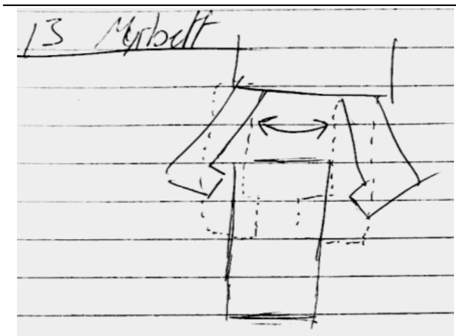
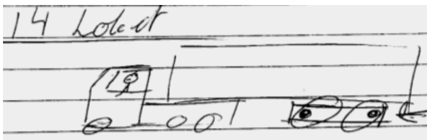
Note: See appendix B.1 for the complete concept tree with listed concepts.

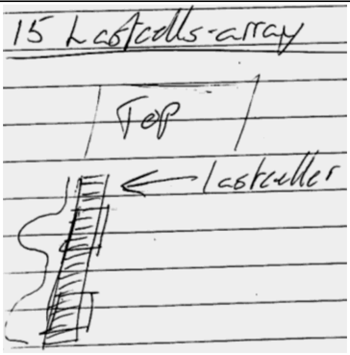
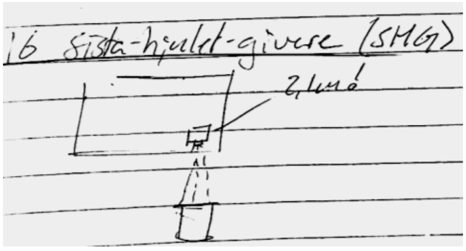
6.1.5 **Results**

In total, over one hundred concept ideas were generated from these processes. Simple sketches and descriptions for the first 16 of these can be found in Table 6.2 below.

Table 6.2 Sketches of the first 16 concepts.

 Tusen nålar: An array of pins recessed in the ground that conform to the shape of the wheel when engaged.	 Tusen nålar I sidled: An array of pins on a structure next to the wheel that conform to the shape of the wheel when engaged.
 Tusen nålar 3: An array of pins recessed in the ground that conform to the shape of the truck's undercarriage when engaged.	 Äggdelaren: Several wires in a row placed on the ground parallel to the docking house that, when lifted, engage with the undercarriage.
	 Bananbarrikad: A bollard horizontally recessed into the ground that pivots up to block the wheel.

Barrikad: A bollard recessed in the ground that raises up to block the wheel.	
 Skivbarrikad: A blocking disc section that pivots out of the ground perpendicular to the wheel, blocking it.	 Skiv(inte)barrikad: A blocking beam that pivots out of the ground perpendicular to the wheel, blocking it.
 Frirull: Low friction wheels engaged on each side of the driven wheels to prevent them from making contact with the ground.	 Sänglampan: The (partial) idea of using a spring system to allow a heavy restraint to be lifted and moved easily.
 Svängarm: A telescopic arm hinged under the dock leveler blocking the wheel when engaged.	 Skjutarm: A scissor mechanism that extends from the docking house outside of the truck to block the wheel.
	 Loket: A fixture that connects multiple wheels together to stop them from turning.

Myrbett: A jaw-like contraption that pinches the wheel when engaged.	
 Lastcells-array: The (partial) idea of using load sensors to detect the position of one or more wheels.	 Sista-hjulet-givare: The (partial) idea of using a sensor to determine the distance from the loading dock to the closest wheel.

6.2 Reflections on the Concept Generation Process

As expected, the process of concept generation resulted in diminishing returns. Initially, the broad brainstorming sessions performed well until idea stagnation was reached at around 50 concepts. At this point, focus was switched to consulting experts and take inspiration from competitors. This gave initial good returns, but as expected stagnated at around 70 concepts. One thing to note is that even though steps to avoid duplicates were attempted, there was a substantial number of new concepts at this stage determined to be too close to previous ones. This realization prompted the creation of the concept tree, seen in Table 6.1.

It was determined, after trying a few different groupings, that the main categories worked best if defined around engagement methods. Using the categories as boundaries for more focused ideation, the number of concepts was expanded too more than 100. Having a clear visual aid to work with helped tremendously with focusing the sessions to single subcategories.

All in all, the concept generation ended with a total of 106 partial and full concepts after one week of work as well as a deeper understating of how trucks and trailers are constructed.

7 Concept Selection and Development

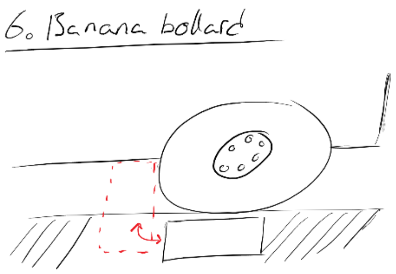
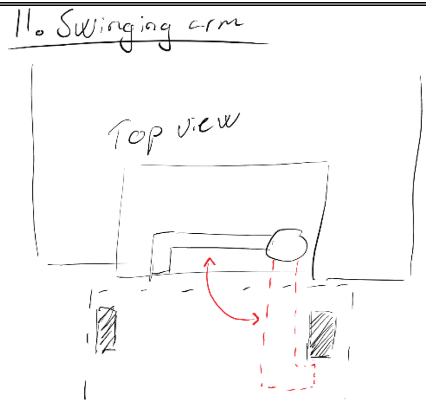
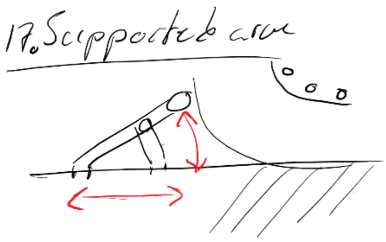
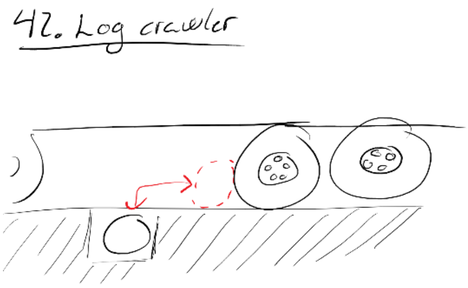
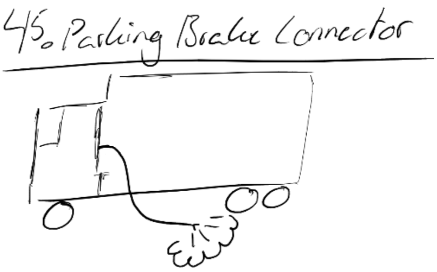
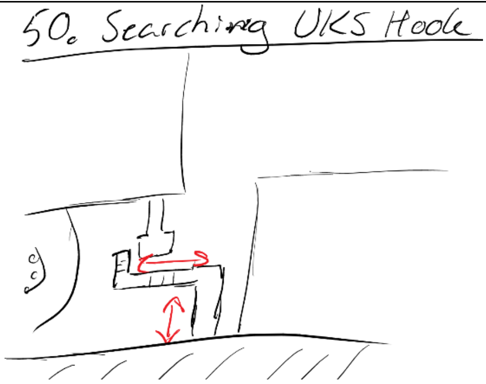
While the goal of concept generation is to produce a large number of concepts (6), this can cause some problems in the concept selection stage. Evaluating each of these fairly would be incredibly time consuming and, often, also frivolous work. In fact, many concepts can be quickly discarded due to obvious flaws that were not considered in the concept generation. The process of eliminating concepts involves methods like voting and screening, aiming to reduce the number of viable concepts to a more manageable amount. The few concepts remaining after the elimination rounds can then be further developed to let them realise their full potential. Following this, another selection round is held to finally choose a concept that can move on to the detail design stage.

7.1 Broad Evaluation

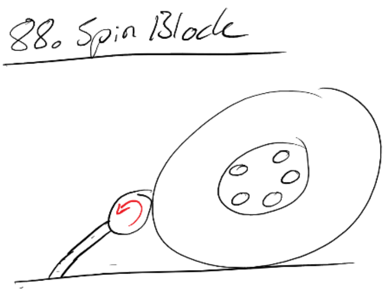
The concept screening phase involved evaluating and narrowing down the possible solutions to reach an optimal concept. This was done in several steps. The first of these was to prune branches (6) that were fundamentally unfeasible (such as using the roof as an anchor point). After this step a voting technique was used to further reduce the number of concepts. Here, each member of the group got to vote once for each concept. The point of the first voting round was to use the available time more efficiently by quickly discarding concepts that lacked any promise. This was achieved by discarding concepts that received no votes.

Round two of voting followed a different idea from the previous round where, instead of quickly going through the concepts, a longer discussion around the concepts was held whereafter votes were cast again. The large number of concepts making it through the previous step led to the decision to this time increase the number of required votes to pass from one to two. The second voting stage also involved what Ulrich and Eppinger calls intuition, where concepts are chosen based on feelings (6). To achieve this combination, a veto system was used. This involved giving each member of the group three veto votes where, if such a vote is cast, the concept is automatically included in further evaluation.

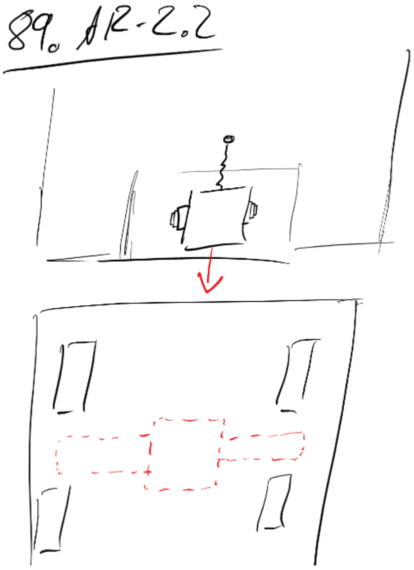
Table 7.1 Concepts after voting and veto.

 6. Banana Bollard: A bollard recessed into the ground that pivot instead to safe space in the ground.	 11. Swinging Arm: A telescopic arm hinged under the dock leveler blocking the wheel when engaged.
 17. Supported Arm: A scissor mechanism that folds up out of the ground to act as a variable block in front of a wheel.	 42. Log Crawler: A bar that slowly moves backwards and blocks all wheels on one axel.
 45. Parking Brake Connector: A connector that force the truck brakes to engage by draining the air from the system.	 50. Searching UKS Hook: A hook that engage with the underrun protection of the truck.

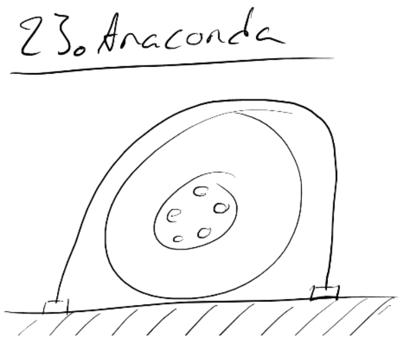
76. Assisted Pit: A pit that the truck wheels get stuck in which only allow exit when an assisting ramp is activated.



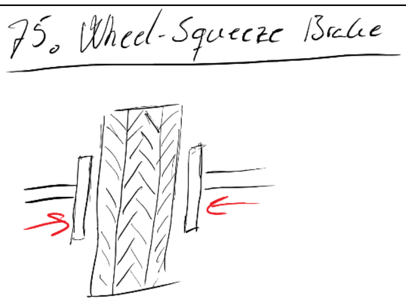
88. Spin Block: A wedge with rollers to prevent the wheels from climbing over that fold out of the ground.



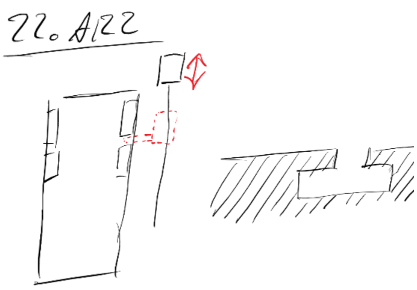
89. AR-2.2: An DE6290AR that follow a recessed track under the truck and engages symmetrically with two wheels from the centre.



23. Anaconda: A cable going around the wheel, tightening to keep it locked in place.



75. Wheel-Squeeze Brake: Two plates that squeeze the wheel from the sides to inhibit movement.



22. AR2: An DE6290AR that follow a recessed track next to the truck and block on of the wheels.

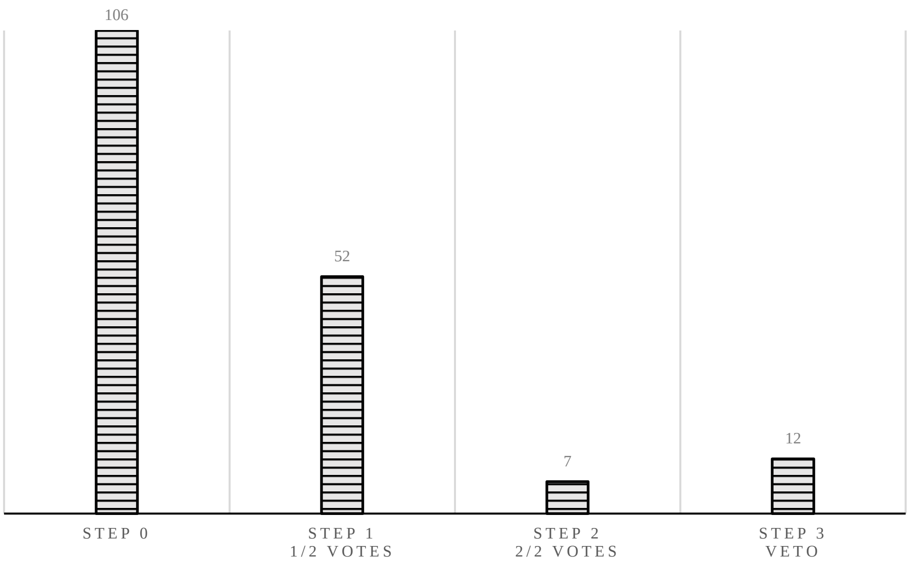


Figure 7.1 Visualisation of the voting process.

7.2 Concept Screening

To evaluate the concepts that had made it through the initial voting rounds and determine which of them warranted further investigation, concept screening was used. This process works by determining a benchmark product (or concept) and then scoring the other rest of them relative to the benchmark's performance. The different comparison metrics were roughly based on the needs found in Table 4.2, though many of them were combined for the sake of practicality.

The categories used for evaluation were:

- Ease of use
- Restraint force
- Complexity
- Fitness (variety of trucks)
- Locking time
- Suited for use in Nordic conditions.
- User safety
- Ease of installation

Following this method (6), all concepts were given a score of -1, 0 or $+1$ in every category, depending on how it compared to the benchmark. The benchmark used was an automatic vehicle restraint system from Assa Abloy (AR, see Figure 2.2*)*. The scores were then summed, and concepts with a score higher than 0 were determined to be worth investigating further.

Table 7.2 Concept screening matrix

	Ease of use	Restraint force	Complexity	Fitness (truck variety)	Locking time	Suited for use in NC*	User safety	Ease of installation	**Score**	Further development
DE6290AR (ref)	0	0	0	0	0	0	0	0	0	
6. Banan-barrikad	0	0	0	0	0	0	0	-1	-1	
11. Svängarm	0	0	0	0	0	1	1	-1	1	✔
17. Stöttarm	0	1	0	1	0	0	0	-1	1	✔
23. Anakonda	-1	-1	1	-1	-1	0	-1	0	-4	
42. Krypstock	0	0	1	1	0	1	1	-1	3	✔
45. Handbromshandske	-1	1	1	1	-1	1	1	1	4	✔
50. Letande uks-lås	0	-1	0	0	0	1	1	-1	0	✔
75. Klämma-däck-broms	0	-1	-1	-1	0	1	-1	-1	-4	
76. Grop med assistans	0	0	0	-1	0	-1	-1	-1	-4	
88. Snurrblock	0	1	0	0	0	1	1	-1	2	✔
89. AR-2.2	0	0	-1	0	0	1	1	-1	0	✔
22. AR 2	0	0	0	0	0	1	1	-1	1	✔

* NC stands for Nordic Conditions.

7.3 Concurrent Improvement with Lean Development

Before final evaluation and selection, some further work was done on the remaining concepts. This step was inspired by the concept of concurrent engineering (17), where parallel development is utilised to save time and improve the quality of the resulting products. Because the limited manpower in this project, the development of the concepts happened concurrently in the sense of development stage, and not necessarily temporally. This step is described by Ulrich and Eppinger as "*combining and improving the concepts*" (6). In addition to concurrent engineering, some methods from lean development were used. As described by Ellis in *Project Management in Product Development* (18) using a single-piece flow instead of batching features can improve the flow of the development process, letting the development team find problems early and make changes accordingly. In practice, this meant trying to get feedback from either field experts or testing for each of the concepts as early as possible.

The combination of these methods resulted in a process that let the team develop each of the concepts and realise their full potential, all while not wasting time on impossible ideas.

7.3.1 **Gathering Field Data**

Part of the lean development process involved making decisions based on real world situations. To gather data for this purpose a field trip to a local logistics centre was conducted. The point of the trip was to gather information about where space was available on a random set of trucks. The measurements taken were:

- Dock to front of rear wheels.
- Dock to back of front wheel set.
- Vertical clearance in front of wheels.
- Minimum vertical clearance between wheel sets.
- Wheel size.

All measurements were taken from a randomly selected set of trucks at DSV in Landskrona. In addition to the truck dimensions, data was collected on the minimum distance between trucks while docked.

Figure 7.2 Truck clearance example.
The arrow shows where the measurement was taken.

Table 7.3 Field data from local logistics centre.

Truck nr.	Type	Dock to Front of rear wheels (m)	Dock to Back of front wheel set (m)	Clearence in front of wheels (cm)	Clearence under (cm)	Wheel size (cm)
1	Semi-trailer	6,2	9,7	50	30	106
2	Distribution	3	7,7	45	25	90
3	Semi-trailer	6,2	10	33	25	105
4	Semi-trailer	6,2	10,8	33	25	100
5	Trailer	4,3	9,7	42	42	100
6	Trailer	4,2	9,7	45	40	83
7	Trailer	4,2	9,7	35	35	83
8	Semi-trailer	6,2	9,7	45	45	103
9	Semi-trailer (short)	3,1	6,2	43	40	80
10	Semi-trailer	6,1	10,8	44	28	100
11	Semi-trailer	6,1	10,8	44	28	100
12	Trailer	4,1	9,8	20	20	85
13	Distribution	4	8	30	30	105

Trucks parked parallel to each other have a separation of 1,4 m or 1,2 m if parked crookedly.

7.3.2 **Resulting Concurrent Improvements with Lean Development**

Below are the main takeaways from the continued development and evaluation of the concepts accepted for further development (see Table 7.2). The names have been translated to English.

7.3.2.1 Swinging Arm

A telescopic arm hinged under the dock leveler. When not in use it is stored completely clear of the loading ground. To engage, it swings out parallel to the ground under the truck and extends to engage with the appropriate wheel. The L shape of the arm catches in front of the wheel and prevents it from moving.

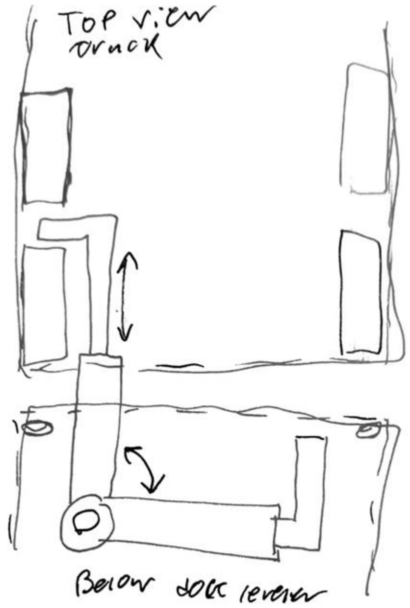
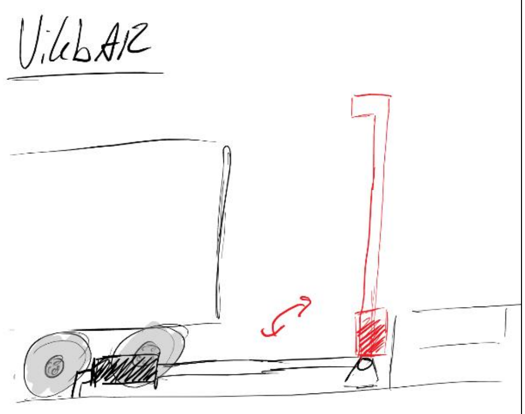
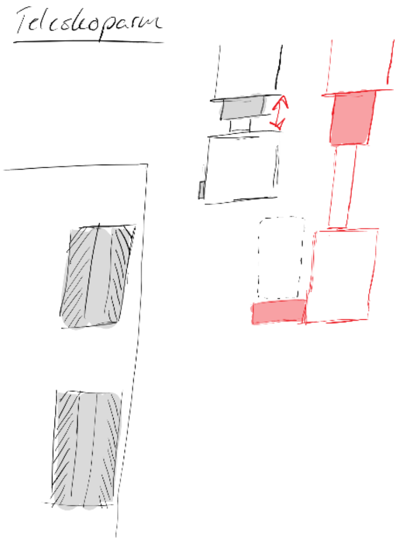


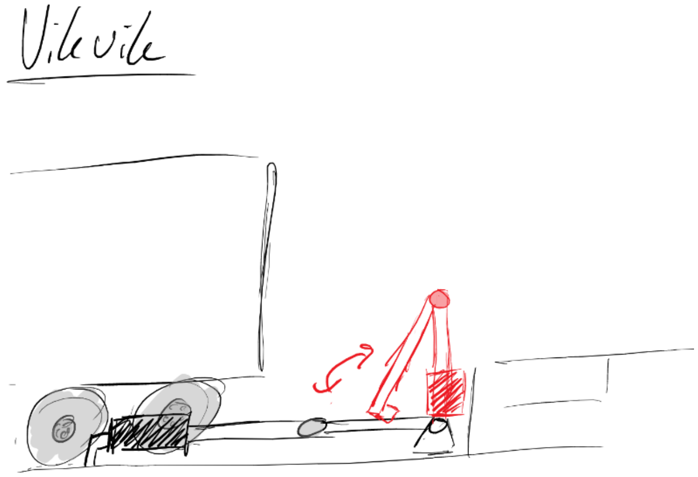
Figure 7.3 Swinging arm sketch.

The low clearance under the trucks (see Table 7.3) prompted a brainstorming session to explore how else a folding, or extending, mechanism could be utilised. The results are illustrated in Table 7.4. The concepts were evaluated in a screening matrix on the same categories as Table 7.2 but with the Swinging arm as the reference. The results of this evaluation can be found in Table 7.5.

Table 7.4 Concepts generated as alternatives to Swinging Arm.

<table>
<tr>
<td>

VikbAR: A rail for the AR robot that folds up vertically at the docking house.</td>
<td>

TeleskopARm: A telescoping arm that pushes out the AR robot next to the truck.</td>
</tr>
<tr>
<td colspan="2">

VikVik: Similar to VikbAR but folds in the middle as well to make the total height lower.</td>
</tr>
</table>

Table 7.5 Screening matrix for Swinging arm improvement

Selection criteria	(ref) Swinging Arm	VikbAR	TeleskopARm	Vikvik
Ease of use	0	0	0	0
Restraint force	0	0	0	0
Complexity	0	1	0	0
Fitness (truck variety)	0	1	1	1
Locking time	0	0	0	0
Suited for use in Nordic conditions	0	0	0	0
User safety	0	-1	0	0
Ease of installation	0	1	0	1
Score	0	2	1	2
Chosen		✔		!
		Chosen to replace Swinging arm		Not different enough to VikbAR

VikbAR description: A gate barrier style rail that fold vertically, parallel to the truck. On said rail an AR style shuttle travels forwards and extends a horizontal bar that behind in front of the appropriate wheel. Illustrations below in Figure 7.4.

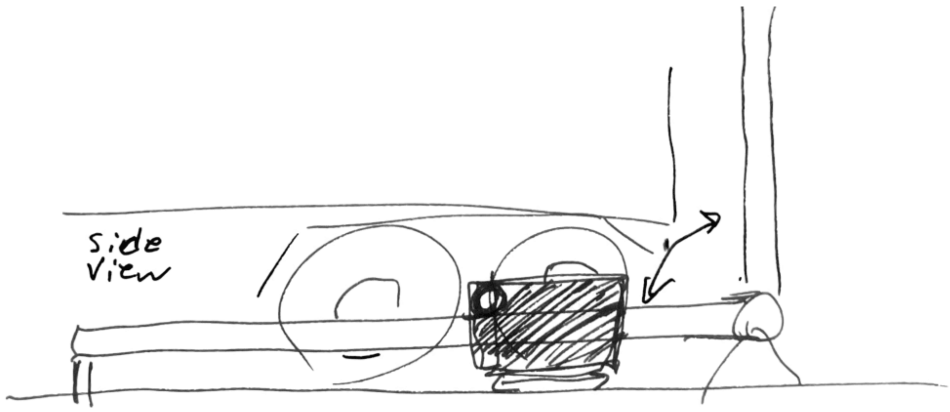


Figure 7.4 VikbAR sketch.

7.3.2.2 Supported Arm

A scissor mechanism that folds up out of the ground to act as a block in front of a wheel. The scissor mechanism allows for variation in angle and height, making it possible to line up the forces with the centre of the wheel (strict compression for main arm and strict tension for the supporting arm). The base of the two arms is embedded in a track in the ground and can be controlled independently to vary position and angle. Just as for VikbAR, an illustration can be found in Figure 7.5 below.

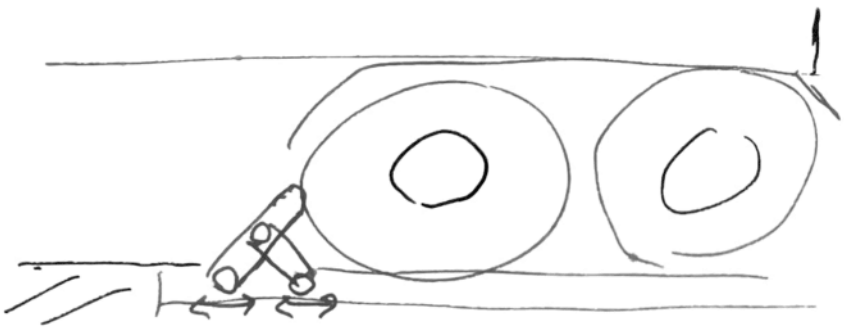


Figure 7.5 Supported arm sketch.

7.3.2.3 Log Crawler

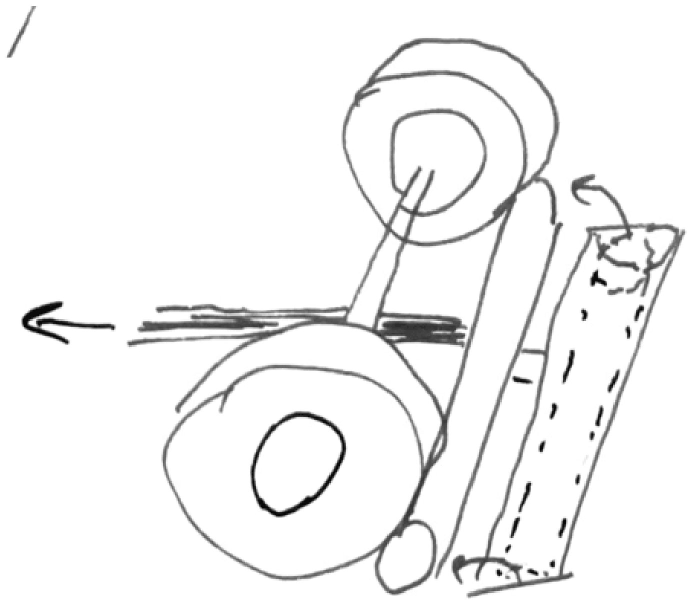


Figure 7.6 Log Crawler sketch.

A bar as wide as the trucks emerges from the ground under the truck and slowly moves towards the dock house until a wheel is hit. The bar is then tensioned against wheels on either side and locked in place (see Figure 7.6). Just as for the Swinging arm, the low clearance measurement prompted an investigation into the needed space for this to work.

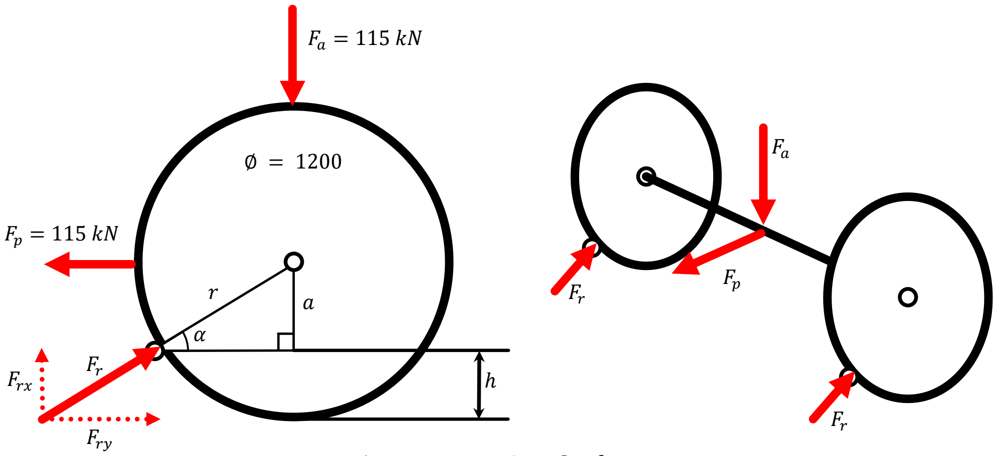


Figure 7.7 Log Crawler forces.

Figure 7.7 shows the pullout force F_p and the axel load F_a balanced symmetrically between the two wheels contact points. This is the load case just before the wheel starts to move over the restraint. To calculate the unknown h, a balance must be created as described in 2.2.1. The vertical forces and the horizontal forces set up to equal zero gives:

$$\uparrow: -F_a + 2F_{rx} = 0 \Rightarrow F_{rx} = \frac{F_a}{2} \quad (1)$$

$$\rightarrow: -F_p + 2F_{ry} = 0 \Rightarrow F_{ry} = \frac{F_p}{2} \quad (2)$$

From Figure 7.7 the following geometric relation can also be determined.

$$a + h = r \Rightarrow a = r - h \quad (3)$$

$$\sin\alpha = \frac{a}{r} \quad (4)$$

$$\sin\alpha = \frac{F_{rx}}{F_r} \Rightarrow \frac{F_{rx}}{\sin\alpha} = F_r \quad (5)$$

$$\cos\alpha = \frac{F_{ry}}{F_r} \Rightarrow \frac{F_{ry}}{\cos\alpha} = F_r \quad (6)$$

Combining (5) and (6) gives:

$$\frac{F_{ry}}{\cos\alpha} = \frac{F_{rx}}{\sin\alpha}$$

Adding (1) and (2) results in:

$\frac{F_p}{2\cos\alpha} = \frac{F_a}{2\sin\alpha} \Rightarrow \frac{\sin\alpha}{\cos\alpha} = \frac{F_a}{F_p}$, and as $\frac{\sin\alpha}{\cos\alpha} = \tan\alpha$ and $F_a = F_p$ as can be seen in 2.2.4 gives:

$$\tan\alpha = \frac{F_a}{F_p} = 1 \Rightarrow \alpha = 45° \qquad (7)$$

Using the geometric relationship between α and h, gained from combining (3) and (4), the required restraint height can be calculated as:

$$\sin\alpha = \frac{r-h}{r} \Leftrightarrow h = r - r \cdot \sin\alpha \qquad (8)$$

Using $\alpha = 45°$ as determined by equation (7) and $r = \frac{\emptyset\, 1200}{2} = 600$ mm from Figure 7.7, a resulting height of $h = 175{,}7$ mm was obtained.

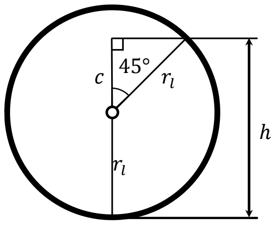


Figure 7.8 Log size.

Using Figure 7.8 the relationship between r_l and h can be obtained by combining $h = c + r_l$ with $\cos 45° = \frac{c}{r_l}$ to get:

$$r_l = \frac{h}{(\cos 45° + 1)} \approx 103 \text{ mm} \qquad (9)$$

Using equation (9), adding the previously obtained value for h and doubling gives the log diameter for such a restraint height. Figure 7.9 below shows that the restraint height would be around 206 mm. Though technically too big according to the clearance data (see Table 7.3) it was determined to still be a feasible idea as that type of problem could be designed around.

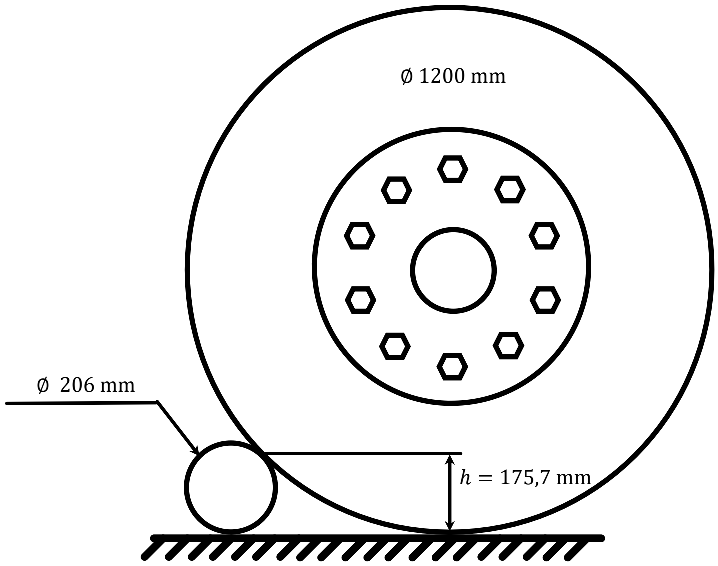


Figure 7.9 Log crawler engaged with a truck wheel.

7.3.2.4 AR2

This concept involves an automatic restraint (AR) being stored under the dock to the side of the truck. When deploying it moves along a rail in the ground and locks in front of the wheel (like the regular DE6290AR). A sketch can be found below in Figure 7.10.

The trip to the logistics centre showed that to accommodate the unit under the dock, the vertical support bar must be removed and replaced with a curved one.

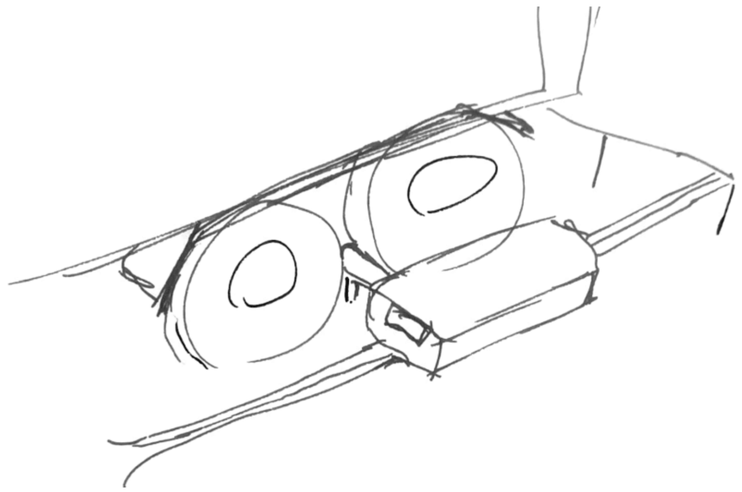


Figure 7.10 AR2 sketch.

7.3.2.5 Spin Block

A wedge with rollers to prevent the wheels from climbing over the restrain, that fold out of the ground and follow a track in line with the truck wheels. Engaging with the wheel in the same way as a normal wedge.

Spin Block was determined to be too similar to the Supported Arm, which prompted a brainstorming session. The resulting concepts were also determined to be too close to the Supported Arm and were thus excluded from the project along with the Spin Block.

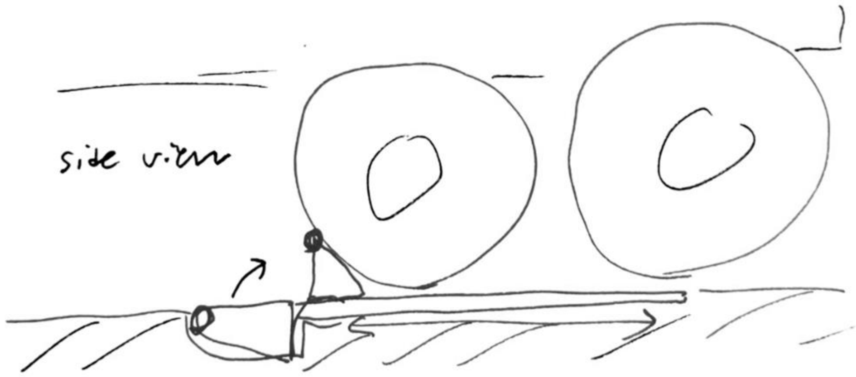


Figure 7.11 Spinn block sketch.

7.3.2.6 Parking Brake Connector

A hose connector stored at the dock that when connected to the truck drains the air from the braking system, causing them to engage. The parking brake was in this concept the actual drive-off prevention. When departing, the truck would have to take some time to refill the system with air resulting in a delay.

This idea has been tested previously by Assa Abloy and the result showed that a truck can pull a trailer with all six wheels locked including a wheel block with no problem. This led to the concept being discarded altogether.

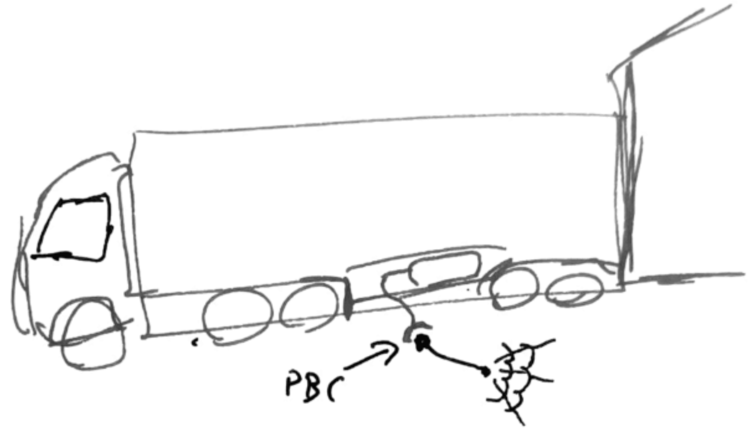


Figure 7.12 Parking Brake Connector sketch.

7.3.2.7 Searching UKS Hook

A hook with two degrees of freedom placed in the centre under the dock leveler. When activated it searches for, and hooks onto the underrun protection. The two degrees of freedom help to accommodate different truck sizes, and in turn positions of the underrun protection beam.

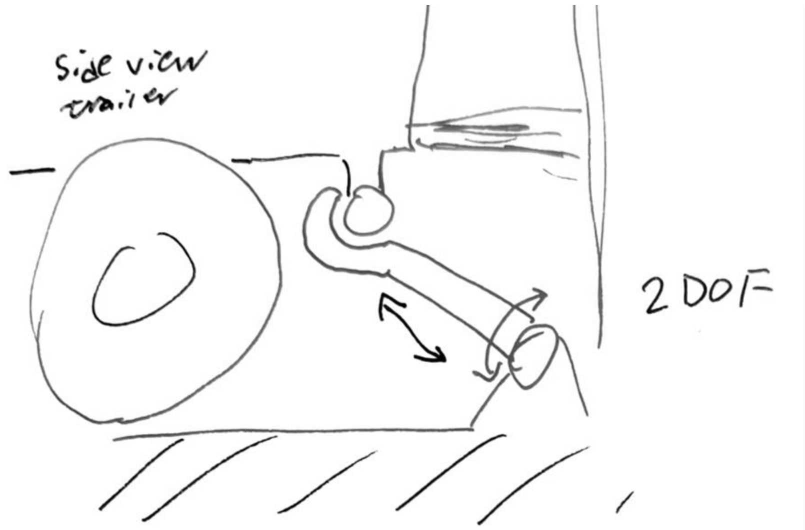


Figure 7.13 Sketch of the searching UKS Hook.

The Swedish Transport Agency require that all modern trucks and trailers with a total mass over 3500 kg fulfil the requirements in 70/221/EEG (19). 70/221/EEG states in annex II.3.6 that "*The rear protective device must have a bending strength at least equivalent to that of a steel beam whose cross-section has a bending strength modulus of 20 cm3*" (20).

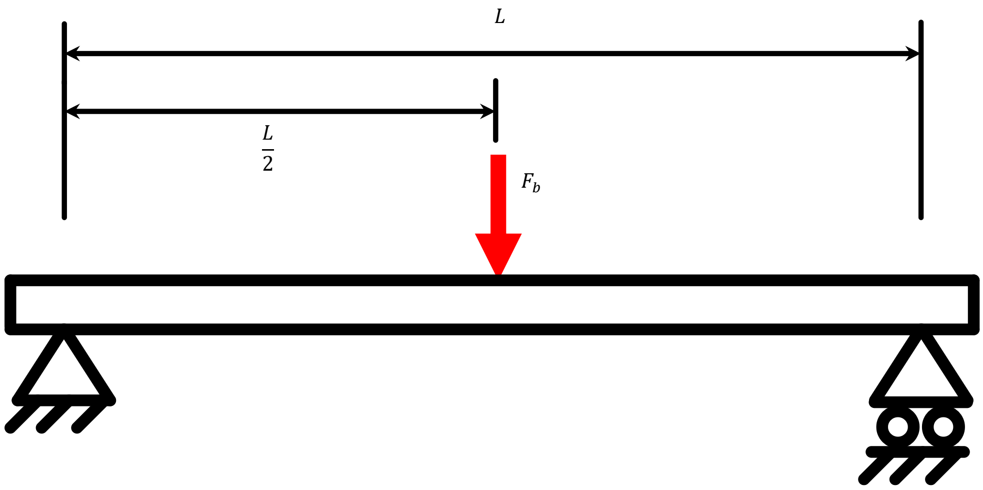


Figure 7.14 Beam bending diagram.

The simplified beam bending situation showed in Figure 7.14 represents the underrun protector being used to restrain a truck using a hook engaged at $\frac{L}{2}$ where F_b is located. As previously described, bending strength modulus W_b is $20\ \text{cm}^3$. The length of the underrun protector is the entire width of a truck, but the distance between the support points is around $1{,}5\ \text{m}$ represented by L. The maximum moment in the beam during bending occurs in the middle and is calculated as:

$$M_b = \frac{F_b \cdot L}{4} \tag{10}$$

The maximum bending moment in a beam is given by $\sigma_{max} = \frac{|M_b|}{W_b}$ (21) eq. 6.8 which can be rearranged to:

$$M_b = \sigma_{max} \cdot W_b \tag{11}$$

Combining (10) and (11) and replacing σ_{max} with the yield strength of a steel beam $\sigma_y = 355$ MPa gives the following equation:

$$F_b = 4 \cdot \frac{\sigma_y \cdot W_b}{L} \tag{12}$$

This gives the result $F_b \approx 20$ kN, or around 17% of the required 115 kN (class 3 system, see 2.2.4). This result caused the UKS Hook to be excluded from further development.

7.4 Concept Scoring

7.4.1 **Development Team**

Using the refined concepts from chapter 7.3 a more in-depth evaluation could take place. As described by Ulrich and Eppinger (6) a weighted scoring system was used for this purpose. To perform a weighted concept scoring, a list of criteria and their relative importance needs to be defined. The criteria list used was the same as in chapter 7.2. The importance was defined by discussing each criterion and giving it an importance score of 1 to 5, where a higher score represents a more important criterion. This was then converted to a proportional weight percentage, adding up to 100%.

In the evaluation one of the concepts was chosen as a general reference, representing a middle ground performance. However, in an attempt to avoid scale compression (6) each criterion was also considered by itself to determine if the reference concept performance accordingly. If not the reference for this criterion was changed to a more fitting reference.

The criteria scores were calculated as the product of the score and weight. These were then summed to give a final score for the concepts.

Table 7.6 Criteria Weights.

Criteria	**Score**	**Weight**
Ease of use	4	17%
Restraint force	!	!
Complexity	2	9%
Fitness (truck variety)	5	22%
Locking time	1	4%
Suited for use in Nordic conditions	5	22%
User safety	5	22%
Ease of installation	1	4%
Total	20	100%

Note: Restraint force is considered a hard requirement.

Ease of use represents most needs regarding ergonomics, intuitive design, and convenience, all of which were all given high importance scores (see Table 4.2). In line with this a score of 4 was awarded to the criterion.

Complexity represents the cost of production, and how hard it is to maintain. This was deemed less important than the function but not unimportant, giving the score 2.

Truck variety fitness was deemed core to the product, resulting in a 5.

Locking time and *ease of installation* was both determined to be less important than the rest and were therefore each given a 1.

User safety was given a 5 as the whole point of the product was to increase workplace safety.

Suited for use in Nordic conditions, being a core part of the project, was also given a 5.

Table 7.7 Concept scoring matrix.

Selection Criteria	**Weight** (Table 7.6)	**Concepts**							
		AR2		**VikbAR**		**Supported arm**		**Log crawler**	
		R	**WS**	**R**	**WS**	**R**	**WS**	**R**	**WS**
Ease of use	17%	**3**	0,5	3	0,52	3	0,52	3	0,52
Complexity	9%	2	0,17	**3**	0,26	4	0,35	3	0,26
Fitness (truck variety)	22%	**3**	0,65	3	0,65	5	1,09	4	0,87
Locking time	4%	**3**	0,13	1	0,04	3	0,13	4	0,17
Suited for use in NC	22%	**3**	0,65	5	1,08	2	0,43	2	0,43
User safety	22%	**3**	0,65	2	0,43	3	0,65	3	0,65
Ease of installation	4%	**3**	0,13	3	0,13	2	0,09	1	0,04
	Total score		2,91		3,13		3,26		2,95
	Rank		4		2		1		3

Note: R stands for rating, WS stands for weighted score, and NC stands for Nordic Conditions.
Note 2: Ratings in bold were used as benchmarks for the criterion.
Note 3: For the complexity criterion, VikbAR was used as the benchmark as it was deemed to better represent middle ground performance than AR2.

7.4.2 **Experts and Stakeholders**

One of the requirements from Assa Abloy was to have a meeting with their experts and available stakeholders at the end of concept generation. To meet this requirement the team decided to hold a presentation of the four remaining concepts. Leading up to the presentation, illustrations and descriptions were prepared as tools for communicating the concepts. The feedback from the presentation was used together with the results from the concept scoring to choose a final concept for further development.

Described below are the final concepts as presented to Assa Abloy experts and stakeholders, complete with functional illustrations.

7.4.2.1 VikbAR

VikbAR was presented as a Nordic version of Assa Abloy's already existing automatic restraint DE6290AR. While the function remained similar, the main difference was the ability to fold the whole structure upright, leaving the loading ground completely clear.

Pros:

- No fixtures or parts in the ground.
- Uses tried and tested technology from Assa Abloy.
- Fundamentally simple mechanism.

Cons:

- A lot of potential energy when in the upright position.
- Heavy and large structure.

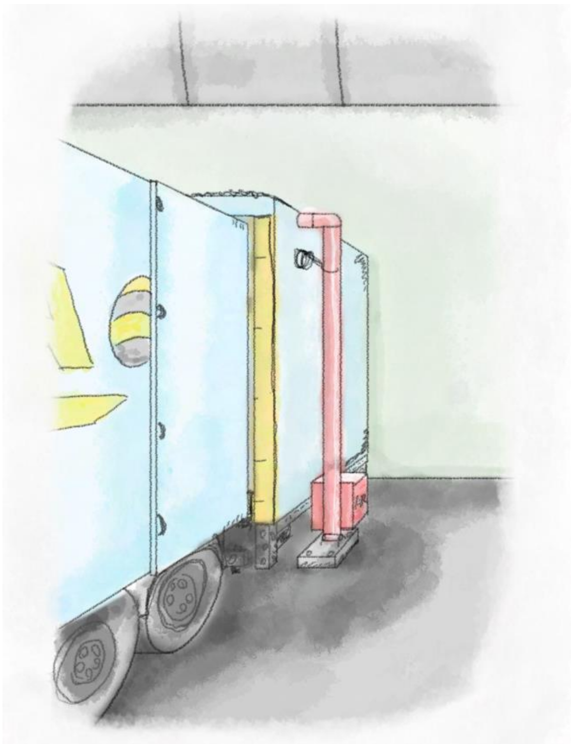


Figure 7.15 VikbAR in its folded state.

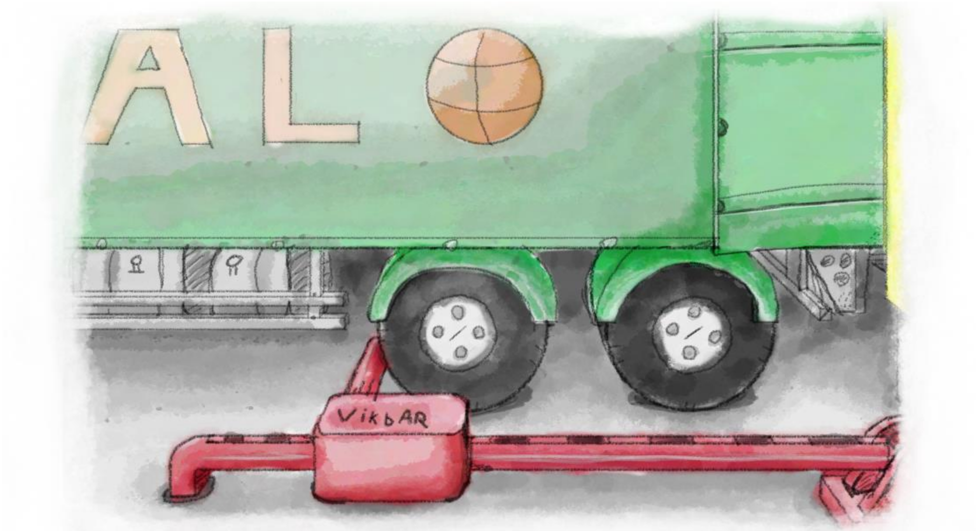


Figure 7.16 VikbAR engaged with a truck.

7.4.2.2 Supported Arm

The supported arm was a promising concept, being mechanically simple while also compatible with many different trucks. The main drawback that was noted was the need for a relatively wide track in the ground to hide the mechanism in. Realistically some sort of cover would have to be used to keep the track clean and flush with the ground.

Pros:

- Relatively small.
- High level of adjustability.
- Engages with only one wheel.

Cons:

- Requires a large track in the ground.
- The two parts must be independently controlled.

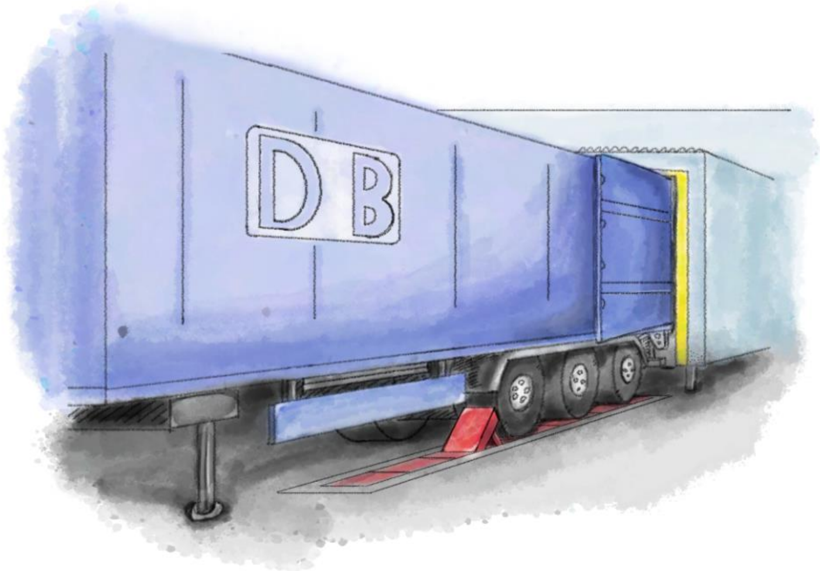


Figure 7.17 Supported arm in use.

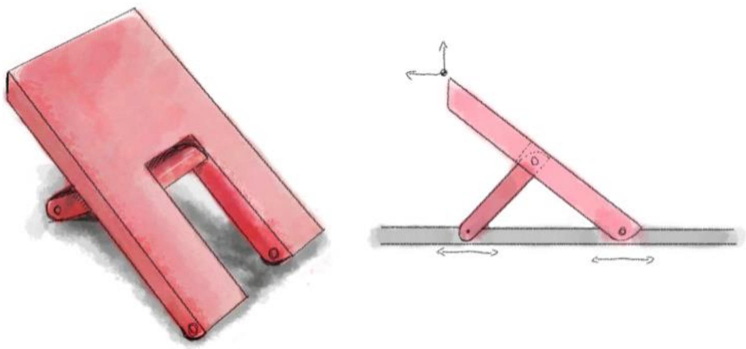


Figure 7.18 Supported arm mechanism.

7.4.2.3 Log Crawler

The log crawler showed a lot of promise with its mechanically simple and robust design. The idea of identifying a wheel contact with current spikes instead of sensors was thought to greatly simplify the design. On drawback of the idea was that it in addition to a track also required a storage area in the ground.

Pros

- Simple in function, requiring no complex sensors or movements.
- Symmetrical tension load avoiding large bending moments.

Cons:

- Close to the maximum vertical clearance under the trucks.
- Stored in the ground leaving a substantial hole when engaged.

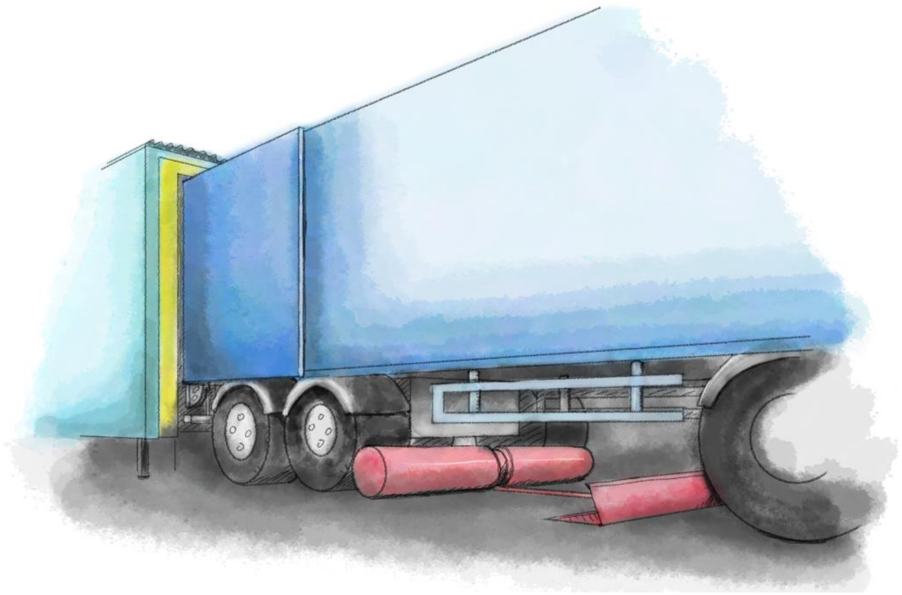


Figure 7.19 Log crawler in use.

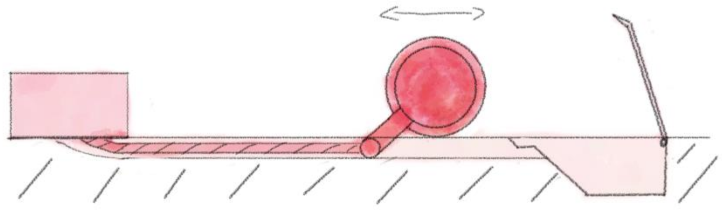


Figure 7.20 Log crawler mechanism.

7.4.2.4 AR2

The AR2 was almost identical to the existing Assa Abloy product DE6290AR, with the only real difference being a track in the ground replacing the over ground beam. Using a similar system was thought to have some benefits, including lower production costs, and removing the need for extensive testing of the locking mechanism. As Assa Abloy provides the docking houses to many of their customers it was seen as realistic idea that a modification could be done to the ground support in order to fit the locking system under the structure.

Pros:

- Uses tried-and-true technology.
- Does not require any large holes.

The cons.

- Small track in the ground.
- Requires a modification to be made on the docking house support leg.

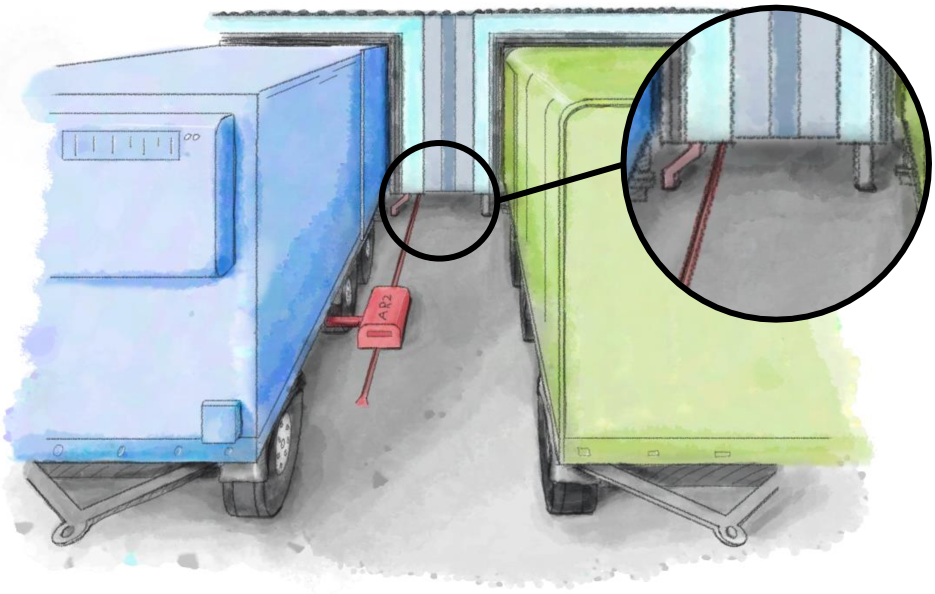


Figure 7.21 AR2 in use.

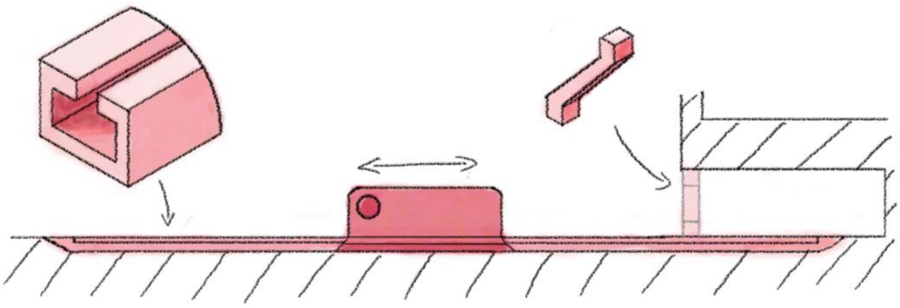


Figure 7.22 AR2 mechanism.

7.4.2.5 Feedback

The main take-aways from the meeting with the experts were:

- Focus on large logistics centres.

The product would likely not be fit for every conceivable loading bay as they vary immensely. The focus should therefore be put on developing a product for large logistics centres to reach a broad market.

- Utilize existing technology, like in VikbAR & AR2.

Using technology already owned by Assa Abloy was presented as an effective way to lower both development and production costs.

- Any opening in the ground will be subject to build up of ice and debris.

Even the idea of weather proofing the holes was met with scepticism as it would complicate the design and add points of failure. It was recommended that the development team completely avoid any concept requiring openings in the ground.

- The loading ground only needs to be clear during snow removal or cleaning.

The restraint system does not have to clear the loading ground after every use. Instead, it only has to do so when the loading ground is to be cleaned or ploughed. This might occur once or twice every day.

7.5 Reflections on the Concept Selection

Due to the successful brainstorming, there were a large number of concepts to evaluate. However, the consensus in the group was that the quality of many concepts was lacking, as they had been mainly used to fill out the concept tree. This judgment prompted the use of an aggressive method for narrowing down the concepts. As seen in Figure 7.1, the first step of voting eliminated more than half of the concepts. However, this was still determined to be too many for the next step and so the decision was made to hold a second round of voting. The second round was a longer and more in-depth investigation that ended in seven concepts remaining. After a discussion, it was decided to incorporate the veto system to allow concepts favoured by certain team members a chance to realise their full potential.

The main concern in the group when performing the concept screening was that the evaluation would not be objective. Mainly because when seeing the result, one might consciously or unconsciously choose to give a certain concept a better or worse rating to skew the results. To avoid this problem, the grading was performed one need at a time, evaluating each concept in comparison to the rest. Importantly, the summation of the total score was not done until all scores had been set. In addition, it was agreed that no changes were to be made to the scores after the fact. This seems to have worked as no complaints were brought up in the design team.

The decision to gather field data was mainly prompted by the continued development of swinging arm (see 7.3.2.1) and log crawler (see 7.4.2.3), both of which rely on a certain vertical clearance under the trucks. To maximize the usefulness of the visit to the logistics centre the decision was made to also gather other critical measurements that could become useful later in the process. Gathering the data took quite some time and because the entire visit needed supervision from an Assa Abloy employee, the number of datapoints gathered was only 13. Of these 13, most was taken from the side of the logistics centre with lower traffic flow, which might have skewed the data towards favouring trailers. This would be consistent with what Assa Abloy experts described about logistics centre design, where one side is commonly used for large, less frequent long-distance freight, and the other side used for smaller more frequent distribution trucks.

The main point of discussion that came up during the concurrent improvement phase was that the Swinging arm concept would be unfeasible due to the required clearance. This, in addition to the VikbAR outscoring the Swinging arm in every category except user safety (see

Table 7.5) led to the decision to continue with only VikbAR.

The Supported Arm needed a more detailed description. Aside from that, no immediate areas of improvement were discovered. After figuring out the required restraint height needed for the Log crawler it was found to be plausible if it engages with two wheels symmetrically. The AR2 (seen in Figure 7.22) required the docking house support leg to be modified. This was discussed with an Assa Abloy expert who thought it reasonable when selling to a customer before construction has begun. It would, however, be more difficult when selling to already operational docks, limiting the possible customers. Despite this, the concept was included in the next part. Discussing the Spinn block it was found to have no real benefit over the Supported arm or Log crawler. To see if there was anything worth further investigation in the concept a brainstorming session was performed. However, this did not yield any promising variations, and the decision was made to discard the idea altogether.

During further investigation of the Parking brake connector the idea was discussed with a supervisor who informed that it had already been tested and proven to not work. This prompted the concept to be discarded.

The searching UKS hook was a concept highly inspired by US restraint systems. Further investigation into the strength of European underrun protectors showed that they are designed differently to their American counterparts. The law requires them to be relatively weak and for them to deform in the event of a collision. The maximum load of 20 kN would be enough for a class 1 restraint system (2), but would leave the beam plastically deformed if a drive away was to occur. The risk of catastrophic failure that allow the truck to leave led to the removal of the concept.

The result of the scoring in Table 7.7 showed that concepts were very close with a spread of worst and best results being only 0,35. To comply with the Assa Abloy requirement of involving their experts, the results of the concept scoring was used in combination with the feedback from the experts to choose the final concept. This also served as a source of outside perspective, discussing things that might have been missed by the design team. Combining the feedback with the scoring matrix showed that the team had underestimated the severity of problems associated with having pits or tracks recessed in the ground. There was a consensus among the experts that such a design element was a major drawback, especially in the case of Log crawler and the Supported arm. Another point of agreement was that using parts from already established technology was a smart move. This promoted the VikbAR and the AR2. Also made clear during the discussion was the fact that the loading ground only had to be clear while ploughing is performed. As the folding operation was one of the main drawbacks of the VikbAR system this was a positive surprise for that concept.

Combining the feedback from the Assa Abloy experts and the concept scoring matrix (see Table 7.7) provided enough information for the finally choose the VikbAR concept for further development.

8 Development of VikbAR

Much of the design work in this chapter took place concurrently, as decisions made often directly affected another part of the system. For clarity, however, the process will here be described one sub-system at a time.

8.1 Sub-System Design

8.1.1 **Product Architecture**

While the general concept of a folding system had been decided at this point more in-depth development had to be done before any prototyping could commence. To begin this process, sub-systems were identified and connected to each other in a product architecture.

A product architecture is a way of describing how a product works by listing the main functions and connections of its sub-systems. The sub-systems should be defined as solution-independent modules of the product. This separation of sub-systems lets the design team generate concepts for the different sub-systems independently, as their connections and desired functions are already known (22). The concept generation and selection can then be done in a similar fashion to how it was done in chapter 6 through 7.

There are of course many, if not an infinite number of, ways to divide the sub-systems. What functions to describe, which parts are to be modular, and which are not were some of the questions the design team was faced with. There is also the question of how in depth the functionality is described. In this project the team strived to divide the system into the main high-level modules present, in order to allow for further development of these sub-systems.

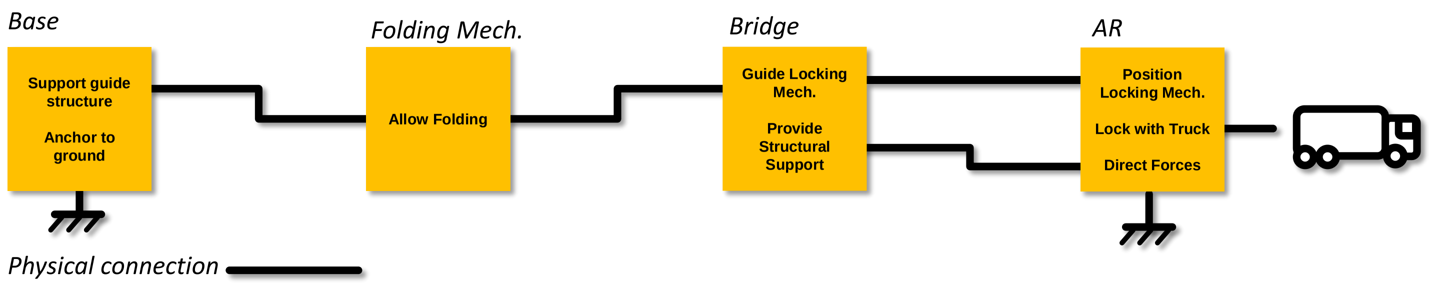


Figure 8.1 Initial product architecture for VikbAR.

8.1.2 **Anchor Points**

One of the first design decisions the team had to make was the question of anchor points. These had to be established in order to allow further design of structural elements supporting the AR. At the end closest to the docking house, it was known that the structure had to be supported by some kind of folding mechanism. The design of the outer end, however, was still undetermined.

The biggest question with regards to the anchoring at the far end was if the ground connection was going to rely on a geometric constraint (see Figure 8.2 top) or friction (see Figure 8.2 bottom). Both options provided several pros and cons. A system relying on a geometric constraint could more easily direct the forces from a truck trying to drive of into the ground. It would also help with alignment and ensure that the positioning of the system would be consistent. As no protrusions from the ground could be allowed a permanent anchor point would have to be recessed into the ground. This would make it prone to filling up with dirt or water, as well as the risk of freezing in place. Some solutions to these problems were explored, such as a lid or using advantageous geometry, but in the end all of them proved either too complex or not reliable enough. This, in combination with the fact that the experts at Assa Abloy were very hesitant about ground recessed systems prompted the design team to decide in favour of the friction solution. This left the team with little flexibility and the final solution became a rubberised bottom plate.

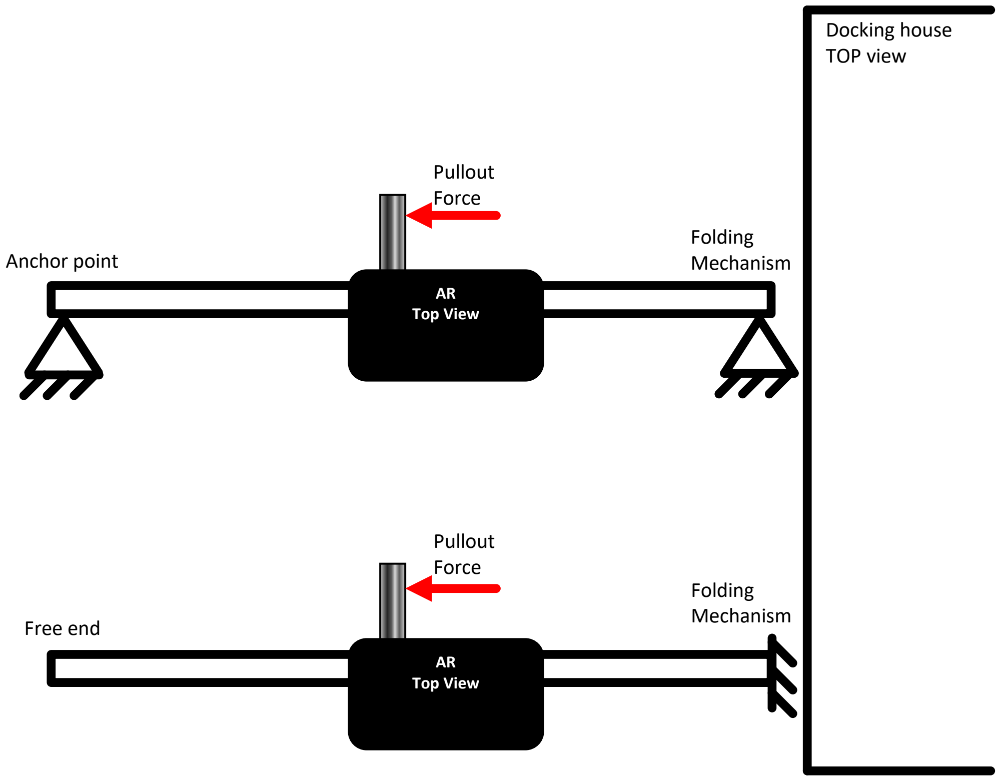


Figure 8.2 Anchor point diagram.
Top: With anchor point. Bottom: Without anchor point.

Another point to consider, especially for the outermost parts, was the possibility of them being accidentally struck by a reversing truck. This could cause serious damage to the system and would in worst case disable the dock until repairs could be made.

To handle this problem the upper part of the end took on a ramp like shape in order to reduce the impact forces. It was argued that while not eliminating the problem this solution would give the driver enough reaction time before hitting any critical structures. The ramp shape, in combination with a rubberised bottom plate, would also serve to direct the forces down into the ground, rather than through the rest of the structure.

To add to the mechanical protection of VikbAR, visual warning elements were also implemented. As can be seen in Figure 8.3 and Figure 8.4, an elevated light was added to improve the visibility of the end, especially in low visibility conditions. The light was combined with a high visibility coting of the bridge to also reduce the inherent tripping hazard prominent in low to the ground obstacles.

Together the ground anchor and the ramp became the foot, seen in the final product architecture in Figure 8.17.

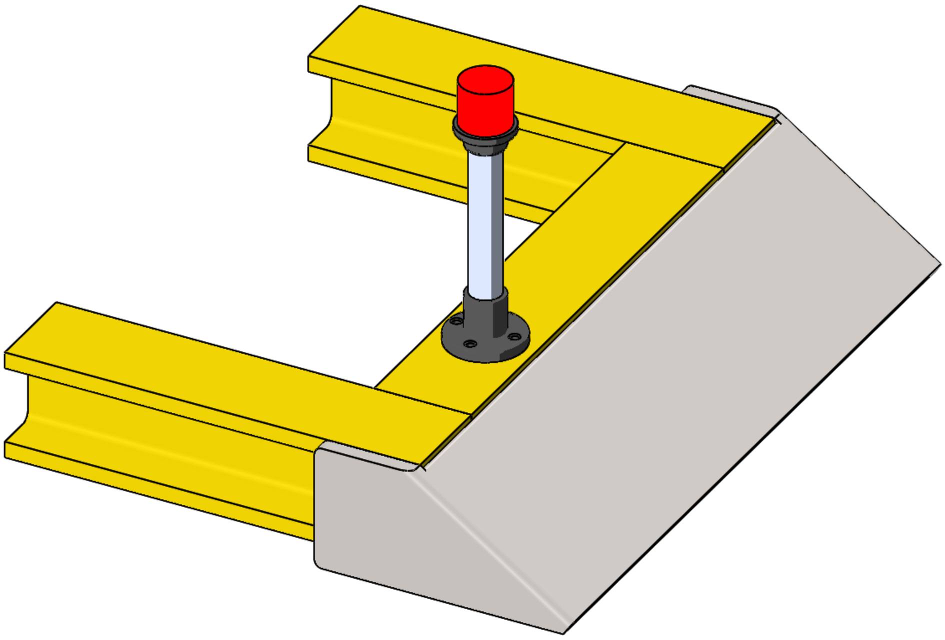


Figure 8.3 Outer ground anchor point isometric view.

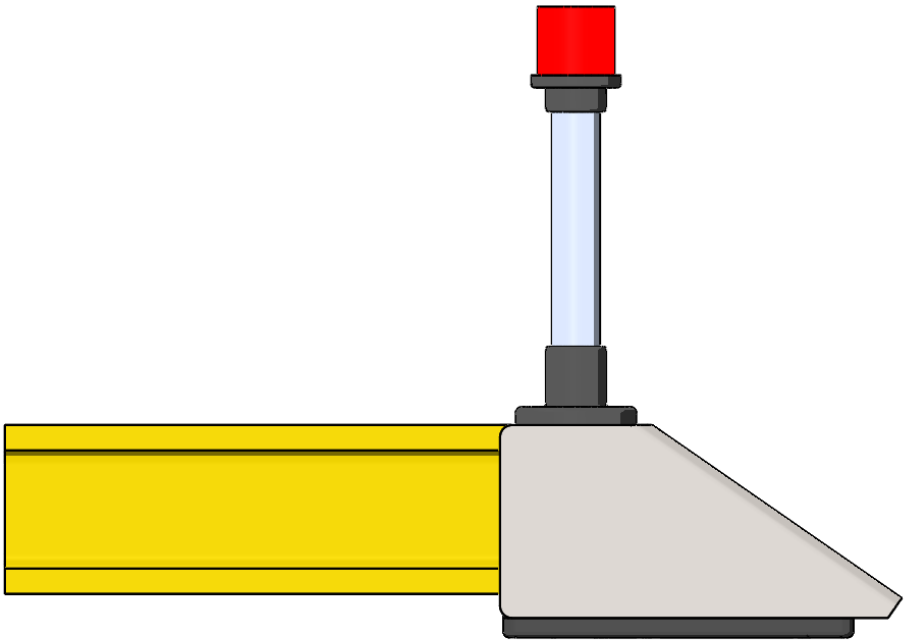


Figure 8.4 Outer ground anchor point side view (foot).

8.1.3 **Beam Design**

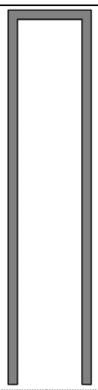
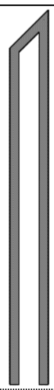
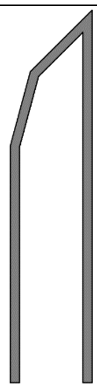
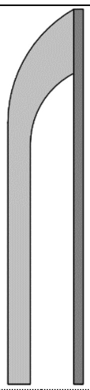
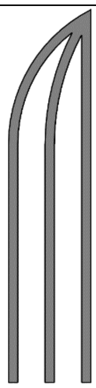
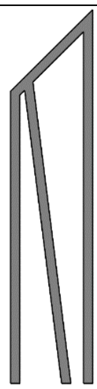
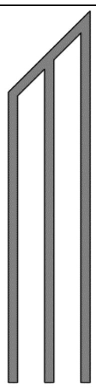
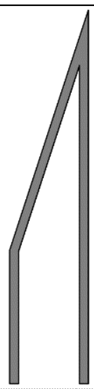
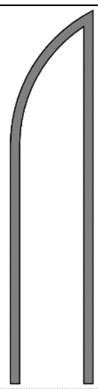
The main folding structure, or bridge, has two main purposes. It should act as a guide rail for the AR, and it should be structurally sound enough to withstand the bending forces from a truck trying to depart (within tolerances). The process of choosing a viable design for the structure involved brainstorming, simulating, and evaluating the results. The designs tested were chosen based on some unique feature that might result in different results. In

Table 8.1 the nine different configurations included in the evaluation can be seen. The evaluation consisted of modelling the configurations in SolidWorks using the HEM120 beam made of S355J2 steel. This beam was specifically chosen as it is the one used in the already existing DE6290AR rail system (3). The FEM simulation was performed by loading the top right (from the image perspective) of the structure with a horizontal load of 115 kN (see Class 3 system 2.2.4). The load was parallel to the main beam, but with an offset of 500 mm to the right simulating the blocking arm. The displacement was measured at the centre of the connection surface for the remote load. A diagram of the FEM simulation can be seen in Figure 8.5.

The configurations [1,3], [3,2], and [3,3] utilised a simple shape optimisation to achieve the best angles or shape for that specific configuration. This was performed using the built-in design study tool in SolidWorks.

Configuration [2,1] in is unique in the sense that a Steel plate with a thickness of 20 mm was used as support instead of an additional beam.

Table 8.1 Beam shapes for simulation.

	1	2	3
1	 Disp. 11 mm Weight 570 kg	 Disp. 10 mm 527 kg	 Disp. 6,6 mm 536 kg
2	 Disp. 16 mm 550 kg	 Disp. 1,3 mm 792 kg	 Disp. 3 mm 755 kg
3	 Disp. 2,7 mm 769 kg	 Disp. 1,4 mm 526 kg	 Disp. 1,4 mm 534 kg

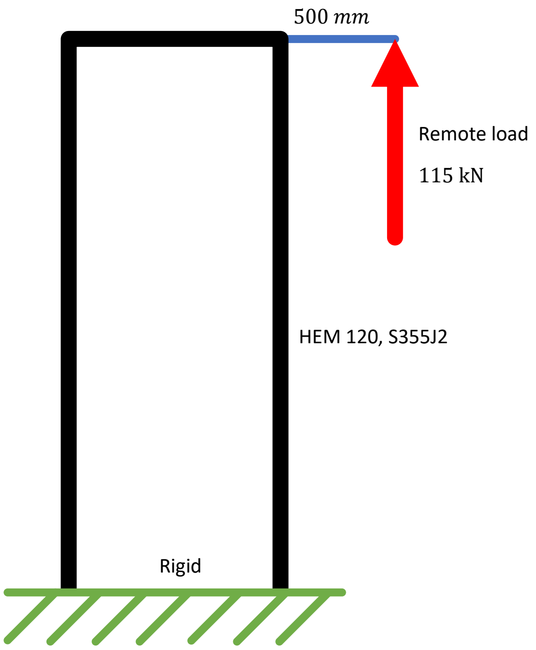


Figure 8.5 FEM simulation diagram.

To include an outside perspective, the configurations were presented to an Assa Abloy expert. The main takeaway from that meeting was that it is expensive to bend HEA120 beams, making [2,2] and [3,3] unfeasible. Combining this with the result of the FEM simulation (see

Table 8.1), the conclusion was drawn that configuration [1,1] was the best for the situation. [1,3] has less displacement but was also more complex. [2,1], [2,3], and [3,1] were too heavy and complex for the given improvement. Both [3,2] and [1,2] did not leave enough room for the AR and would have to be lengthened to work, lowering their rigidity.

8.1.4 **Folding Axis**

One of the high-level design decisions in question was what axis the folding was to rotate around. While the initial idea was to elevate the mechanism to an upright position, the thought of instead folding parallel to the ground was explored. The idea was that this solution could offer several benefits over folding upright, such as lower forces, simpler mechanics, and increased overall safety.

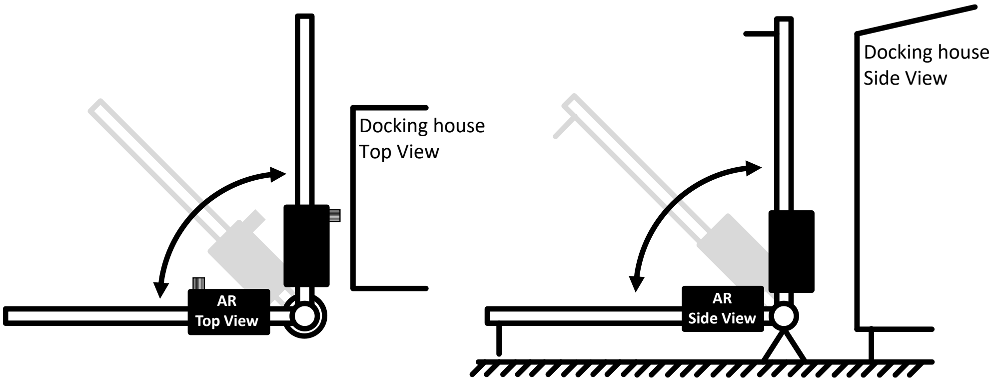


Figure 8.6 Folding axis.
Left: Parallel folding. Right: Vertical folding.

A parallel folding system seemed promising but proved to have one critical flaw. At loading bays there are often several dock houses next to each other with minimal space in between. The problem with this is that the width of a docking house plus the space to the next one is not as wide as the bridge is long. This means that in order to make a parallel system work they would have to overlap when folded. Overlapping them in this way would cause the bridge to stick out a maximum of $\sim$1,5 m, or about $3x$ the expected distance. This could not be tolerated and caused the focus to shift from parallel to upright folding again.

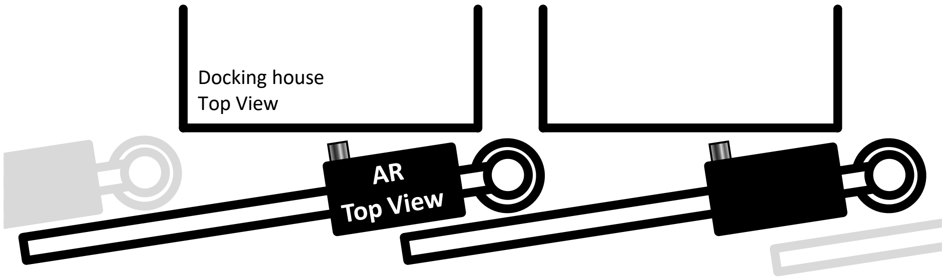


Figure 8.7 The overlapping problem of parallel folding.

Though not without problems of its own, a vertical system did not seem to have any critical flaws that would make the concept entirely unfeasible. The main questions with the concept were how to address the safety concerns, and how to implement a robust folding mechanism.

8.1.5 **Folding Mechanism**

For the folding mechanism several ideas were explored. Of these the top three candidates were:

8.1.5.1 Hydraulics

A hydraulic cylinder could be placed under the bridge, connecting it to the base plate. By extending the cylinder the bridge would be forced into an upright position.

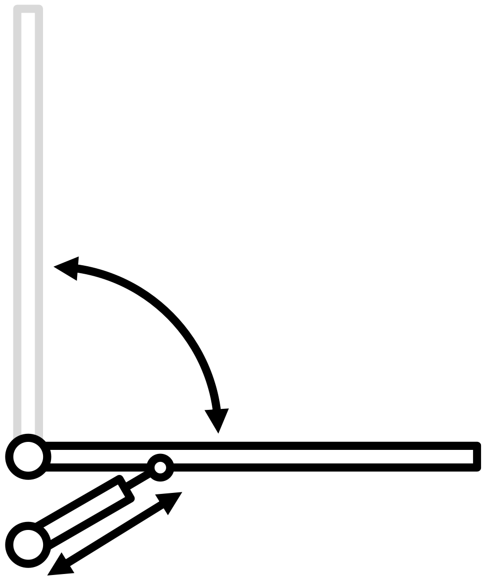


Figure 8.8 Concept of hydraulically controlled lifting.

While this seemed promising at first there were a couple of issues that led to the concept not being selected. At first the idea was to connect the hydraulics to the already existing ones in the dock leveler. This was, according to Assa Abloy experts, not possible as the existing pump would not have been strong enough and the tanks too small. The cost and added complexity of a hydraulics system was ultimately deemed too high for the folding mechanism.

8.1.5.2 Gears

The second idea for a folding mechanism was to make use of gears mounted on the folding axis, inspired by *Bascule Bridges* that lift to let ships pass underneath. As this method has been used for bridges it was assumed to be capable of heavy loads.

Figure 8.9 The bascule bridge in Malmö. (23)

This idea seemed promising to begin with, as it was mechanically simpler than hydraulics and made use of counterweights to significantly lower the stress on the motors. The main question then became: how can a counterweight be utilized? There are of course many possibilities, but the main ones explored in this project was the use of gravity to counterbalance the bridge or using springs or torsion bars to store the potential energy.

One option could be to use springs in tension when the bridge is down. Springs are already used as counterbalances for many of Assa Abloy's industrial doors, meaning that the company is familiar with the technology. When speaking to Assa Abloy experts about the idea, however, it was made clear that to be able to counteract the torque of the bridge several large (and expensive) springs would have to be installed. As there was little room for this, and due to economic factors, the idea of using springs was determined not to be feasible.

Using torsion bars was also an interesting idea that, unfortunately, had to be left rather quickly. To achieve the moment needed to support the mass of the bridge, the size of the torsion bar would have to be larger than the available space would allow.

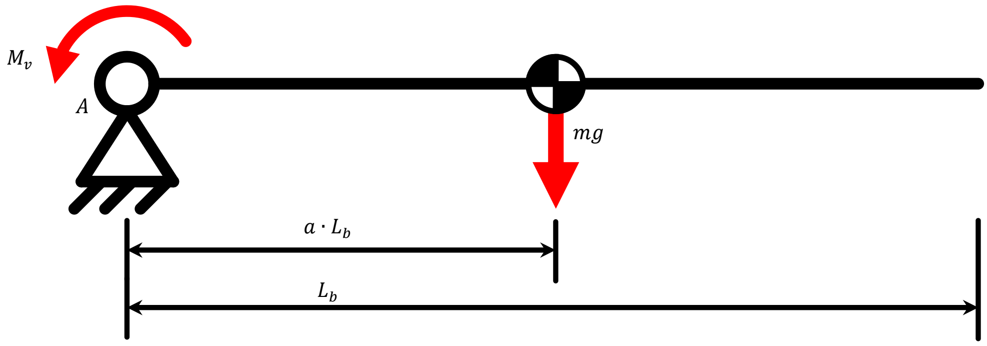


Figure 8.10 Torsion bar moment balance.

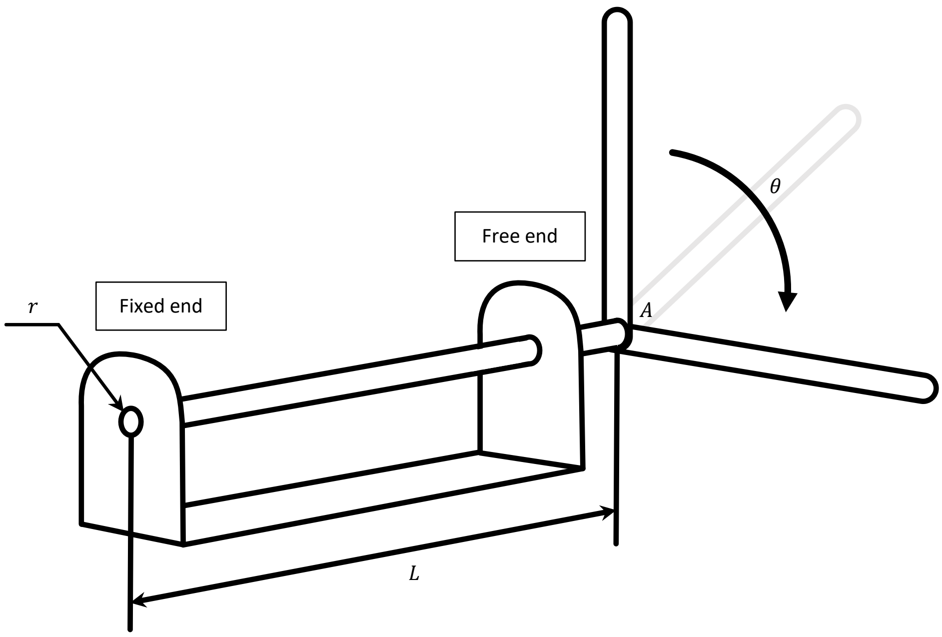


Figure 8.11 Torsion bar geometry.

Following the diagram in Figure 8.10 a moment balance is created using the mass and the moment created by the torsion bar.

$$M_v = a\,L_b mg \qquad (13)$$

Using equation (13), the torsion bar radius r (see Figure 8.11) is determined by the following equations:

$$w_v = \frac{\pi\,r^3}{2}$$ (21) eq. 6.78 where $D = 2r$ and $d = 0$

$$\tau_{max} = \frac{M_v}{W_v}$$ (21) eq. 6.76

$\sigma_e = \sqrt{3\tau^2}$ (21) eq. 3.30

Combining (6.76) and (3.30) gives:

$$\sigma_e = \sqrt{3 \cdot \left(\frac{M_v}{W_v}\right)^2} \quad (14)$$

Adding (13) and (6.78) to (14) and placing r on one side results in:

$$r = \sqrt[3]{\frac{2\,a\,L_b\,mg}{\pi\sqrt{\frac{\sigma_e^2}{3}}}} \quad (15)$$

Calculating using the estimated values of $L_b = 5$ m, $a = \frac{1}{3}$, $m = 1000$ kg, $g = 9{,}82\,\frac{\text{m}}{\text{s}^2}$, and using a high grade spring steel with a 1,5 safety factor (2) $\sigma_e = \frac{1000}{1{,}5} = 667$ MPa gives $r = 0{,}03$ m.

To calculate the required length of the torsion bar the following equations are needed:

$\theta = \frac{M_v\,L}{G\,K}$ (21) eq. 6.75

$K = \frac{\pi r^4}{2}$ (21) eq. 6.77 where $D = 2r$ and $d = 0$

$G = \frac{E}{2(1+\upsilon)}$ (21) eq. 3.13

Combining 3.13, 6.75 and 6.77 with (13) gives:

$$\frac{\theta\,E\,\pi\,r^4}{a\,L_b\,mg\,4\,(1+\nu)} = L \quad (16)$$

Using $\theta = \frac{\pi}{2}$ (rad) $= 90°$, $E = 210$ GPa and $\nu = 0{,}3$ as standard numbers for steel, r from the previous result and the same numbers as used before, the length L is calculated to $L = 9{,}86$ m. Or in other words, too long.

The idea of using a counterweight to balance the system with only gravity was quickly discarded as there was not enough space for the weight, or to extend the lever. It could, however, be possible to make use of a pulley system to redirect the forces to strictly vertical ones. This could make more room for the counterweight and possibly allow for longer travel.

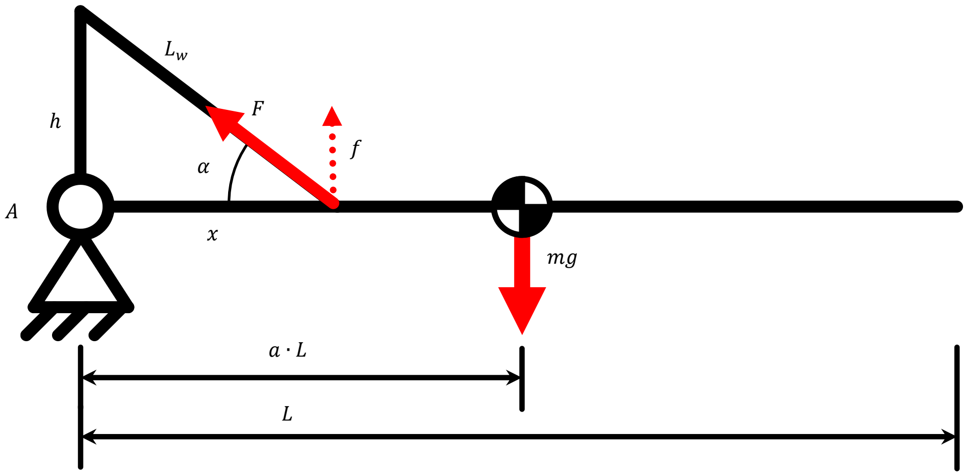


Figure 8.12 Counterweight connected to pulley system.

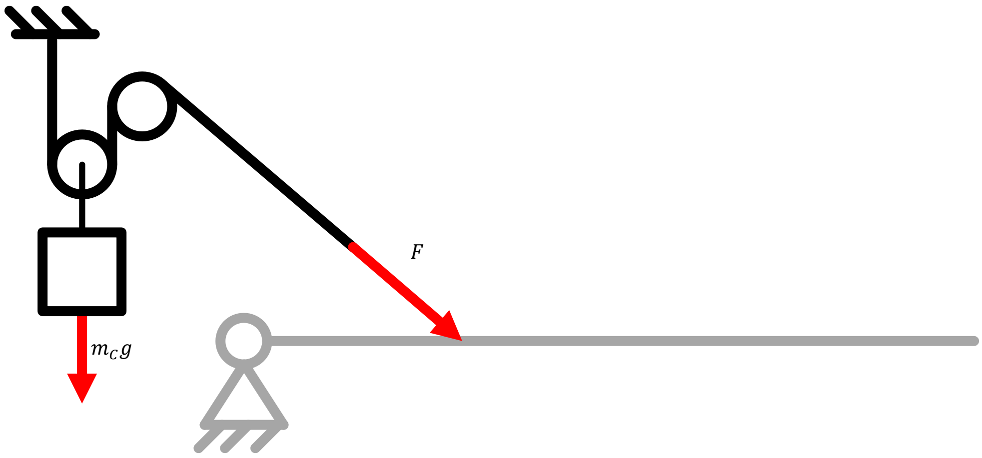


Figure 8.13 Counterweight disadvantage.

Using the diagram in Figure 8.12 the wire force F required to lift can be calculated.

$$\tan\alpha = \frac{h}{x} \Rightarrow \alpha = \operatorname{atan}\frac{h}{x} \tag{17}$$

$$\sin\alpha = \frac{f}{F} \Rightarrow f = F \cdot \sin\alpha \tag{18}$$

Utilising a moment balance around A, the relation between f and mg can be established.

$$f \cdot x - aL \cdot mg = 0 \tag{19}$$

Combining (17), (18), and (19) and simplifying give the following result.

$$F \cdot \sin\left(\operatorname{atan}\left(\frac{h}{x}\right)\right) \cdot x - aL \cdot mg = 0$$

$$\Rightarrow F = \frac{aL \cdot mg}{x \cdot \sin\left(\operatorname{atan}\left(\frac{h}{x}\right)\right)} \tag{20}$$

The length of wire required to be pulled in can be determined using the following equation using the triangle in Figure 8.12.

$$x^2 + h^2 = L_w^2 \Rightarrow L_w = \sqrt{x^2 + h^2} \tag{21}$$

As can clearly be seen, to allow the weight to lift the bridge, the connection point distance from the pivot x must be zero to allow h and L_w to be equal. This is not possible which is reflected in in equation (20) by the $\frac{h}{x}$ term. To make this possible, a solution like the one showed in Figure 8.13 must be used. To calculate the relation between F and mg the following equation is used as you trade distance for force.

$$2F = m_c g \Rightarrow m_c = \frac{2F}{g} \tag{22}$$

Combining (20) and (22) removes the influence of g and results in the following equation.

$$m_c = \frac{2 \cdot aL \cdot m}{x \cdot \sin\left(\operatorname{atan}\left(\frac{h}{x}\right)\right)} \tag{23}$$

Using estimates for a total weight of around $m = 1000$ kg, a height of $h = 1{,}5$ m, the attachment point position $x = 1{,}5$ m, and a centre of mass position of $a = \frac{1}{3}$ the required force F can be calculated using (23) giving $m_c \approx 3100$ kg.

While this mass was deemed unreasonable the idea of using wires still had some merit to it and a modification on the idea came to mind. Could a winch be used to elevate the bridge without the need for a counterweight?

8.1.5.3 Winch

Using a winch could offer mostly the same benefits as a counterweight, being low complexity and cost, while avoiding the need for a counterbalance. Using equation (20) and the same estimations as above and using gives a wire load of $F \approx 16$ kN. Even consumer winches, like the Power Winch from Meec Tools (24), are often rated for higher loads than this, further reinforcing the feasibility of their use in this kind of system.

Ultimately using a winch system to raise and lower the bridge seemed like the most promising solution and was the one the development team agreed to use.

8.1.5.4 Winch Tower

While the winch and the wire might hold the force required to lift the bridge, the mounting point also needed to be strong enough. To make sure of this, the SolidWorks FEM tool was utilised. The simulation involved testing different beams and supports and evaluating the result with a safety factor of 1,5 (2). The beam length and force angle used the values determined when calculating the winch force, as it was deemed to be a good ergonomic height for eventual maintenance work. An additional height of 0,1 m was added to allow some clearance below the bridge beams. The FEM simulation was performed with the beam being rigidly connected to the ground. A force of 16 kN was applied to the top surface of the beam along a 45° angle towards the ground. The material used was construction steel S355J2.

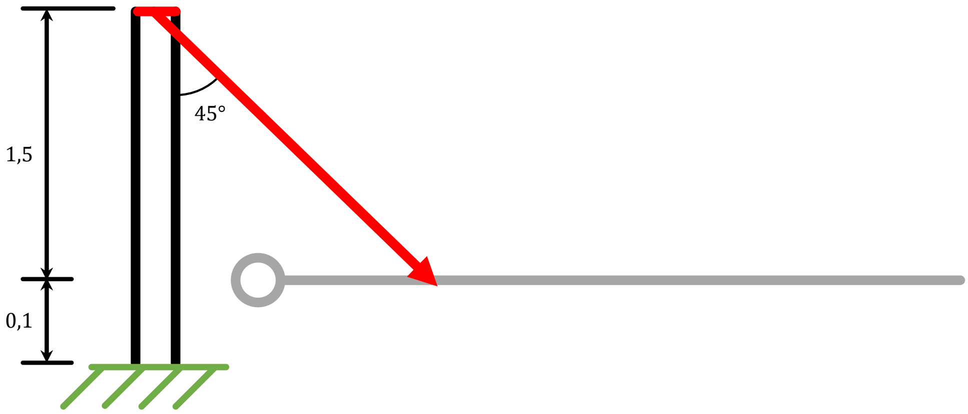


Figure 8.14 FEM Winch tower.

Table 8.2 Tower bending FEM result.

BEAM		σ_{max} MPa	Mass kg	Max disp. mm
HEM 120		71,6	82,9	3,8
HEM 120	w. support	89,3	84,4	3,2
UPN 140		333	25,4	23
UPN 140	w. support	397	26,4	29
HEA 120		199	31,6	13
HEA 120	w. support	241	34,4	8,9
HEA 140	w. support	179	40,9	6
IPE 160		188	25,1	8,8
IPE 160	w. support	232	26,6	6,9

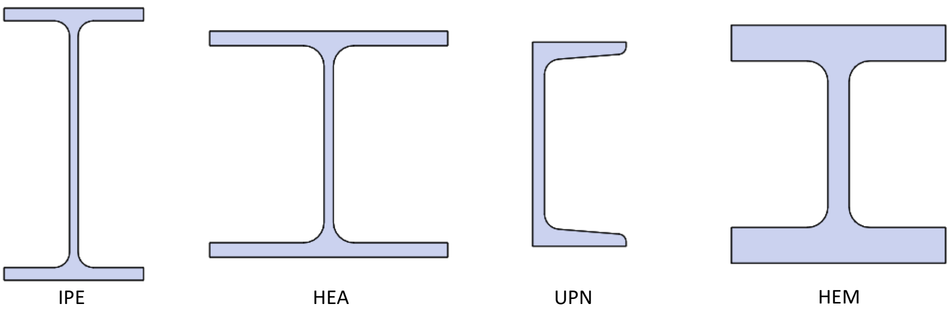


Figure 8.15 Principal beam shapes.

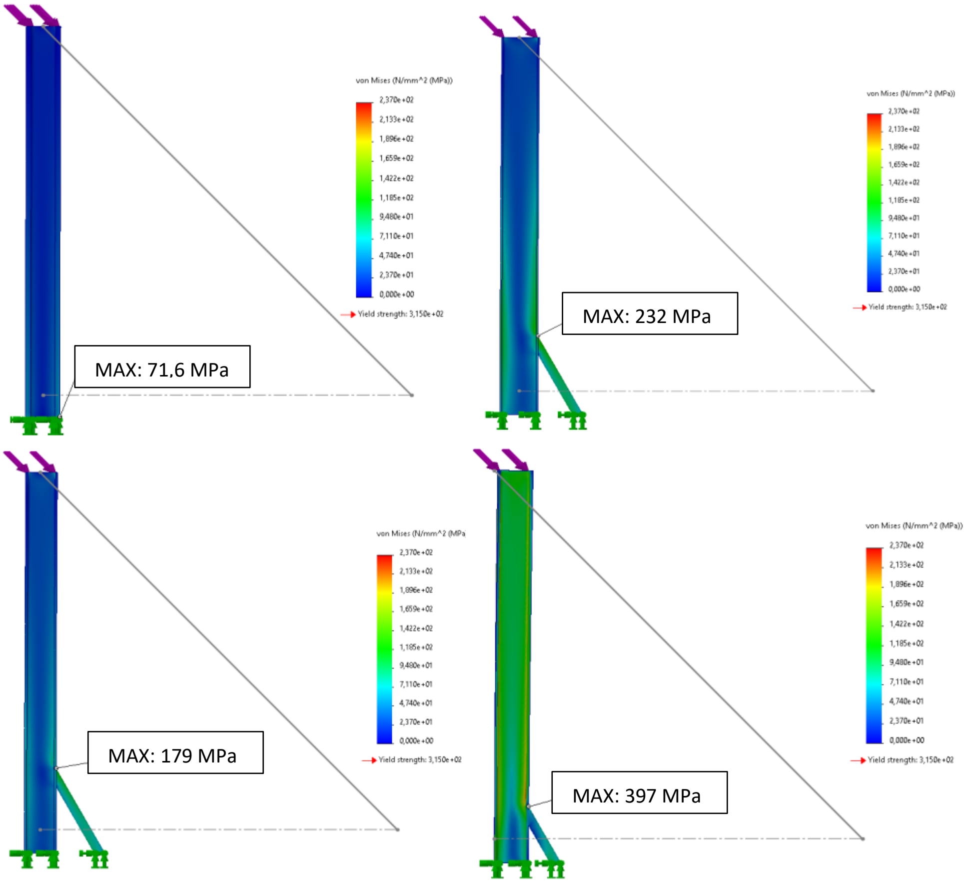


Figure 8.16 Selection of Tower FEM results.
Top left HEM 120, top right IPE 160 w. support,
bottom left HEA 140 w. support, and bottom right UPN 140 w. support.

When analysing the results from the simulation, the conclusion was drawn that some sort of support was necessary. As can be seen in the top left of Figure 8.16 the stress concentration is located at the weld placement whereas it has moved towards the support in the top right figure. A HEM 120 beam with support could be discarded on the basis that it was too good when compared to a safety factor of 1,5, resulting in $\frac{\sigma_y}{1{,}5} = 237$ MPa for $\sigma_y = 355$ MPa. The U profile of the UPN beams resulted in off-axis bending and a high stress concentration in the corners, seen in the bottom right of Figure 8.16.

The beam with the most potential, and the one chosen to be used, was the IPE 160 with support. It resulted in a maximum stress below the 237 MPa limit, but not by so much that it was completely overkill. It was also the lightest one of the beams able to withstand the load.

8.1.6 **Results Design Process**

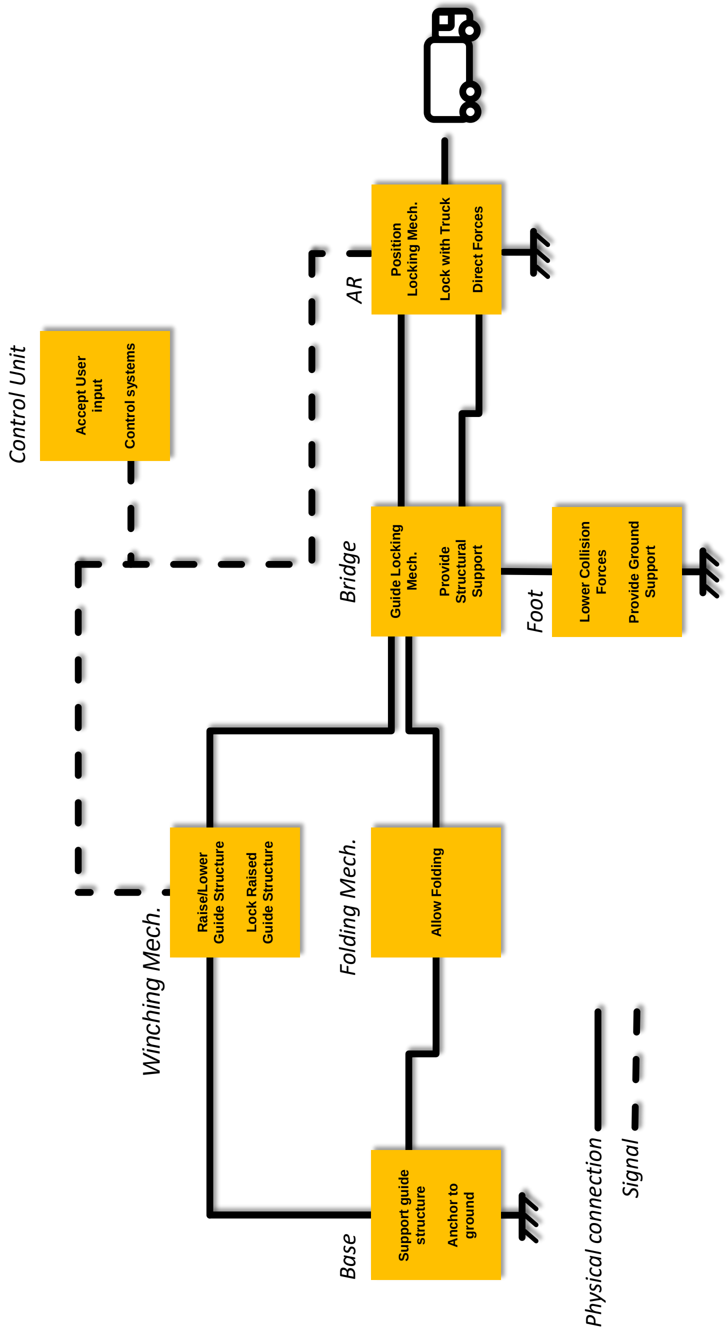


Figure 8.17 Final product architecture.

8.2 Prototyping

The use of prototyping served two main purposes in this project. The first one was to allow the development team to test their designs and make alterations if necessary. For this purpose, 3d-models of the product were made in SolidWorks. This allowed for exact measurements to be set, as well as some mechanical simulations to be made.

The second use of prototyping was to communicate the product functionality to people outside of the development team, such as management at Assa Abloy. For this purpose, a $1:5$ scale model was built.

8.2.1 **CAD**

The following figures shows the rendered model.

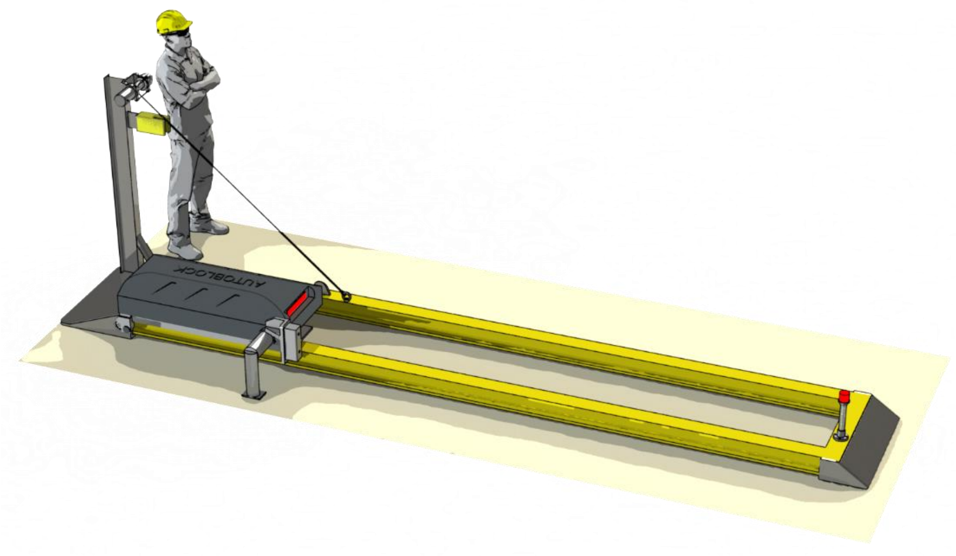


Figure 8.18 CAD model overview with a $185\ cm$ tall man for reference.

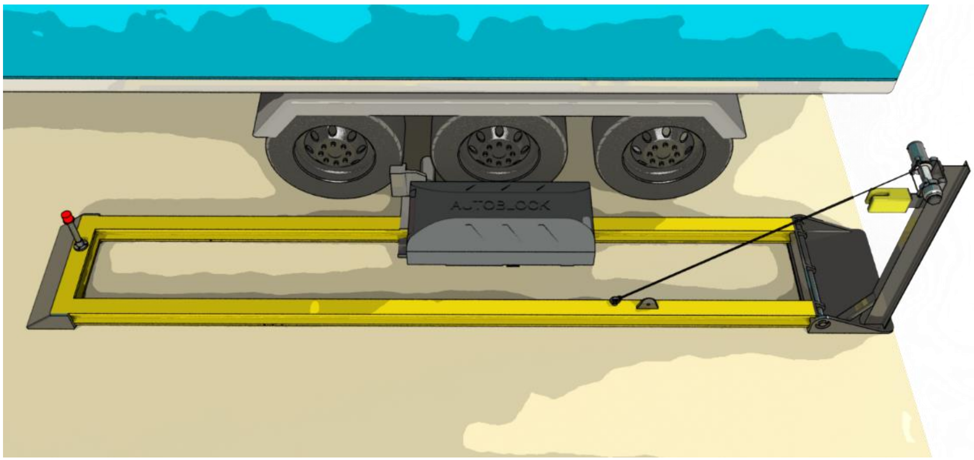


Figure 8.19 VikbAR engaged to a truck wheel.

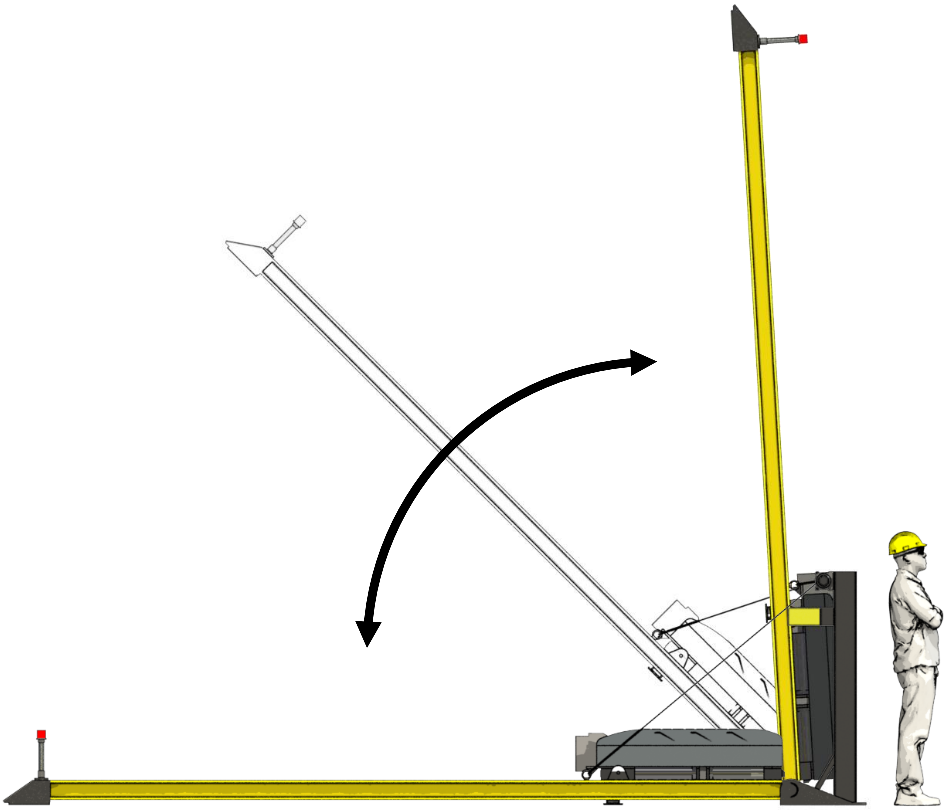


Figure 8.20 VikbAR folding process with a $185\ cm$ tall man for reference.

8.2.1.1 FEM simulation

To evaluate the prototype, SolidWorks FEM tool was used. To simulate a real load case, a rigid force transfer block was used instead of a remote load to apply the pullout force more accurately. The block was designed to have the same area of engagement as the AR system, the same support leg, and the same size blocking arm. The block was bonded to the model and the load was applied to the end of the blocking arm.

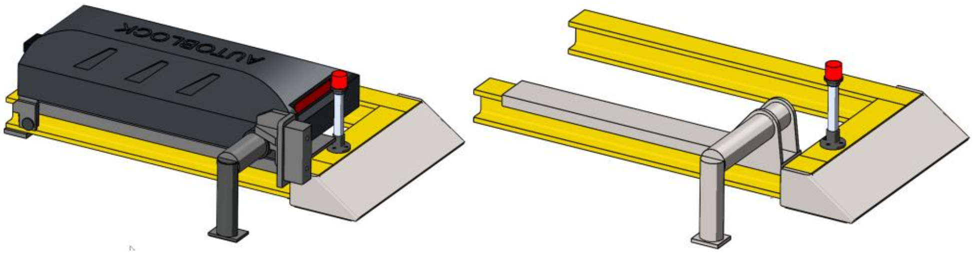


Figure 8.21 Force transfer block.
Left: AR. Right: Simplified force transfer block.

As this simulation was used as a proof of concept, the decision was made that spending time accurately defining welds, specifying exact measurements for ground anchors and bearings would be an unnecessary step this early in the development process. Instead, the welds were replaced with fusing the model into one monolith part, the bearings simulated using the bearing connector provided by SolidWorks, and the ground anchors simulated by fixing the ground plate to the ground plane. The foot and the support leg used a frictionless contact to the ground plane to simulate a worst-case scenario. The force applied to the structure was determined by combination the requirement of 115 kN for a class 3 restraint (see 2.2.4) and the recommendation given by the engineer responsible for the AR at Assa Abloy. During a meeting, force distribution between the support leg and the beam was discussed. The main takeaway was that around 70% of the force applied would be directed into the ground through the support leg of the AR. Thus, a force of 115 kN was applied to the end of the blocking arm where $115 \cdot 0{,}7 = 80{,}5$ kN was vertical pointing down. The material used was S355J2, same as when evaluating the beam structure in 8.1.3.

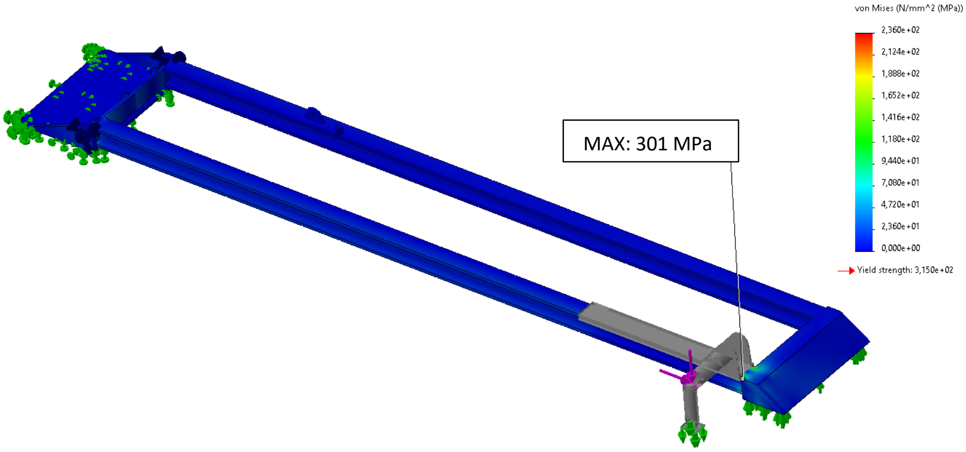


Figure 8.22 FEM Result overview.
Colour scale: Blue 0 MPa, Red 237 MPa.

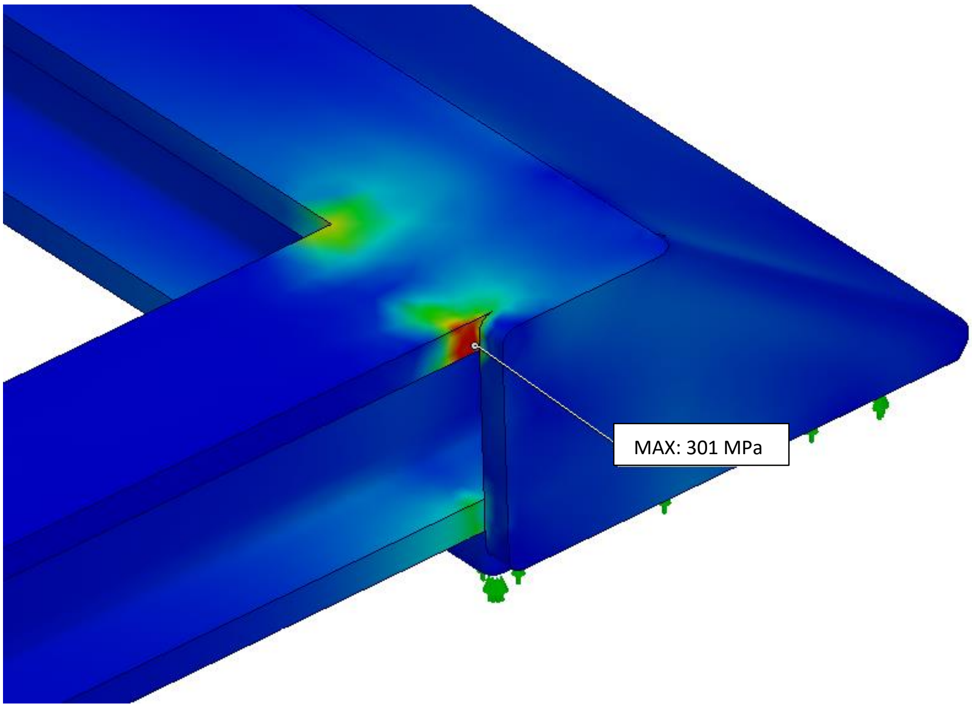


Figure 8.23 Stress concentration showed without force transfer block.
Colour scale: Blue 0 MPa, Red 237 MPa.

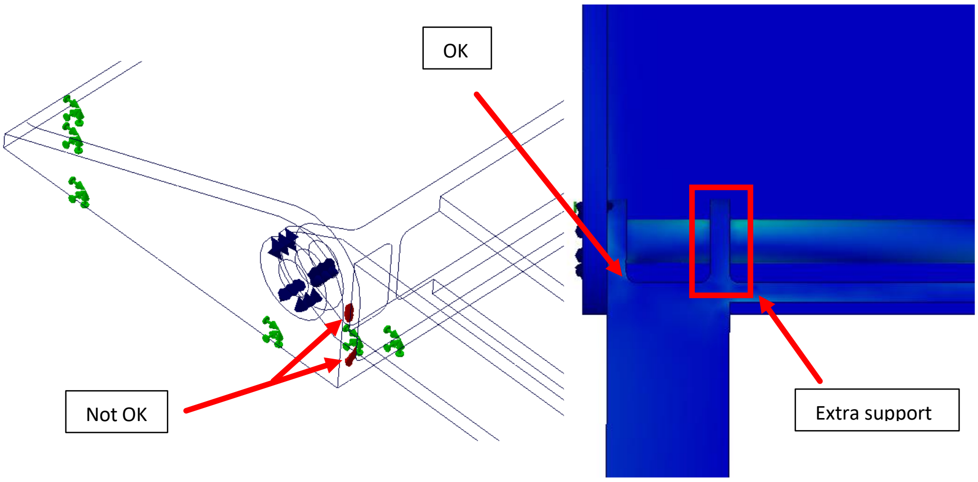


Figure 8.24 Hinge reinforcement.
Left: Iso view without support. Right: Top view with support.

Before reaching the result seen in Figure 8.22 a problem area seen in Figure 8.24 had to be addressed. The initial design, displayed as a wireframe model on the left in Figure 8.24, shows a stress concentration in the corner. To ease the load an extra support was added on both sides, showed to the right in Figure 8.24. This fix resulted in a more even stress distribution. The final simulation, seen in Figure 8.22, shows all parts except the point of contact with the force transfer block sitting comfortably below the maximum allowed stress. Figure 8.23 shows the stress concentration that occurs where the rigid force transfer block interacts with the beam. This is partially a consequence of making the force transfer block rigid and would likely not be a problem in the real world. Had the concept not been designed around using the existing AR system, a potential path to solve such an issue would be to investigate if different rail configurations could reduce stress concentrations.

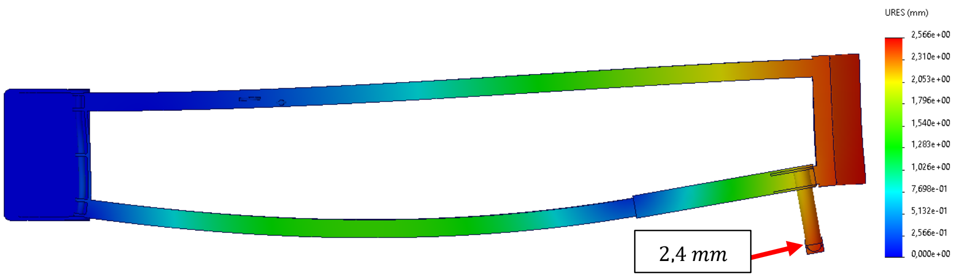


Figure 8.25 Deformation under load.
Top view with 100x deformation scale.

From this simulation, metric 35 in Table 5.3 could be evaluated. It is described as *maximum allowed creep under load*, with a marginal value of 50 mm and an ideal value of < 10 mm. The deformation result seen in Figure 8.25 shows that the end of the blocking arm moved 2,4 mm , well below the ideal value.

8.2.2 **Physical Model**

The physical models were created mainly by 3D-printing parts from the CAD model. To showcase the VikbAR functionality, the hinge, winch, and blocking system were modified to be functional while also possible to print. The parts were printed in a Prusa Mk4 using a combination of PLA, PETG, and TPU. They were mostly glued together using CA and hot-melt adhesive. The latter being especially suited for applications such as filling tolerance gaps resulting in robust connections.

The physical models were mainly used to demonstrate the functionality of the product for people outside of the development team.

Figure 8.26 1:5 scale physical model.

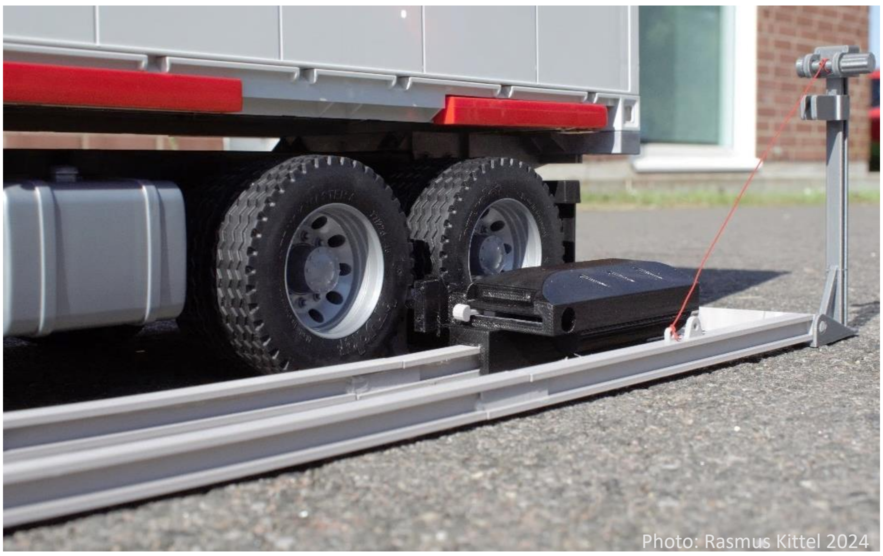


Figure 8.27 1:16 scale physical model showcased next to scale model truck.

8.3 Risk Analysis

To ensure the safety of the system a primary risk analysis was carried out. This included identifying potentially hazardous situations, as well as suggesting remedies for these.

According to ISO 12100, risk is a function of severity of harm and probability of occurrence (5). These parameters were estimated using Table 8.3, resulting in a risk level for the given situations (see Table 8.4).

Table 8.3 Risk assessment scoring guide (25).

Severity to health (patient, user, technician)	
1	No injury or other effects on health.
2	Minor, barely visible injury, effect on health barely perceptible.
3	Injury and/or other effects on health moderate but manageable without clinicians.
4	Injuries and/or health effects caused to an extent that shall be treated by clinicians, permanent consequences might occur.
5	Injuries and/or health effects caused to an extent that shall be treated by clinician, permanent consequences occurred, possible death.
Likelihood (patient, user, technician)	
1	Incredible: Incidence of less than 1 out of 50.000 users; incidence of less than 1 out of 1.000.000 usages.
2	Improbable: Incidence of less than 1 out of 8.000 users; incidence of less than 1 out of 100.000 usages.
3	Occasional: Incidence of less than 1 out of 2.000 users; incidence of less than 1 out of 10.000 usages.
4	Probable: Incidence of less than 1 out of 500 users; incidence of less than 1 out of 5.000 usages.
5	Frequent: Incidence of less than 1 out of 50 users; incidence of less than 1 out of 2.000 usages.

Table 8.4 Risk assessment.

Risk No.	Issue/risk description	Type of Injury	Severity	Likelihood	RISK level	(Possible) Root Cause		Potential Preventive Action		
1	Uncontrolled descent	Crushing / Impact	5	2	10	Wire failure		Regular inspections and quality check	Fail safe system	Dual wire system
2	Uncontrolled descent	Crushing / Impact	5	1	5	Winch failure		Regular inspections and quality check		
3	Uncontrolled descent	Crushing / Impact	5	2	10	Attachment failure		Regular inspections and quality check		
4	Uncontrolled descent	Crushing / Impact	5	2	10	Catastrophic structural failure		Regular inspections and quality check		
5	Uncontrolled descent	Crushing / Impact	5	3	15	Loss of power		Actively disengaged breaks		
6	Unauthorised controlled descent	Crushing	4	5	20	Operator error		Proximity sensor	Emergency stop	Surveillance system
7	Unauthorised controlled descent	Crushing	4	5	20	Unauthorised operation		Operator identification		
8	Unauthorised controlled descent	Crushing	4	1	4	Control unit malfunction		Regular inspections and quality check		
9	Caught in winch system	Crushing	4	3	12	Inattentive operator		Emergency stop	Cover	Trained operators
10	Pretension malfunction	Pinching	4	2	8	Something between wheel and bar		Emergency stop		
11	Pretension malfunction	Pinching	4	2	8	Incompatible truck		Emergency stop		
12	Caught in rail system	Pinching	3	2	6	Exposed mechanism		Cover		
13	Person on top of bridge while lifting	Fall	4	1	4	Misuse of equipment		Instruction manual	Trained operators	
14	Tripping hazard	Tripping	2	4	8	Parts close to the ground	Poor visibility of parts	Increased visibility	Safety rail	
15	Walking collision	Bruising	2	4	8	Parts close to the ground	Poor visibility of parts	Increased visibility		

Table 8.4 showed that the most severe risks had to do with unauthorised or wrongful operation of the system. This indicated a strong need for qualified personnel to operate the system and to prioritise its ease of use.

It was also notable that most of the potential injuries had a severity rating of 4 or 5. This meant that they would likely be severe ones, requiring immediate medical attention.

8.4 Reflections on the Development of VikbAR

It seems that many of the sub-systems, while supposedly independent in the architecture, greatly affect each other's design. As the development happened concurrently for many of the sub-systems, the design process was much more intertwined than described in this report. Even the product architecture changed throughout the development process, both in scope and preciseness (see Figure 8.1 and Figure 8.17).

The sub-systems designed here do not make a final product. In fact, it was known that several of them would have to be improved, or even changed entirely, should the product become reality. However, these systems were designed to be a proof of concept for the general solution, demonstrating that a system like this could work.

Due to the scope of the project, there was simply not enough time to go any deeper into the development.

The prototypes were made to show the system to people outside the development team and demonstrate its functionality. However, both the physical and digital models proved to be valuable tools within the design team as well. Facilitating communication of design choices and concepts that were otherwise difficult to explain. The main physical prototype ended up at a $1:5$ scale instead of the initially planned $1:16$. This decision was made after seeing the $1:16$ model in real life and concluding that it was very small. So small that it could not be used effectively to demonstrate the functionality during the presentation at Assa Abloy. And so, it was decided to construct a larger $1:5$ scale model as well.

As for the risk analysis, focus was put on realistically dangerous situations. As discussed before no exact final dimensioning had been done and so not all potential risks could be assessed. The ones listed in the analysis, however, were general ones which were connected to the concept as a whole. In other words, while the risks listed are sure to exist there might be additional ones depending on future design choices.

The worst risks having to do with crushing was not surprising as it was a known problem with the design. However, the fact that it was only to be in the upright position when cleaning the docking zone and the redundancy of the upright locking mechanism were somewhat alleviating factors. Other solutions had other problems, and, in this case, folding upright was seen as a necessary trade off to keep the design simple.

9 Discussion

In most projects not everything goes according to plan, as was the case with this one. The initial time schedule was, naturally, created before the start of the work. This approach, while necessary, was flawed in some ways. One of the main problems was that the scope of the project was much greater than the team had experience with. This led to some confusion about where time was to be allocated since there seemingly was so much time to work with; something that would later prove not to be the case. In the end the initial time schedule was used as a guideline for the work, though some changes had to be made along the way.

One major change of plan was with regards to the building of a physical prototype. As mentioned under chapter 8.4 two physical prototypes were made as the first one was deemed too small. However, what was not mentioned was that the initial schedule called for the construction and testing of a full-scale model. About seven weeks of work was originally dedicated to building and testing of the prototype. However, when approaching the scheduled start of prototyping there were some uncertainties with regards to the readiness of the concept. What such a large-scale prototype would achieve was also put into question. For the prototype to have any significant impact on the projects results a considerable amount of time would have had to be put into developing tests for the prototype, as well as interpreting the results. In the end the development team and Assa Abloy agreed that too much concept development would have had to be sacrificed in order to construct a full-scale prototype, and so the development process was instead prolonged. It was at this stage that the construction of a scaled down model was proposed. Not taking up nearly as much time, it was seen as a good compromise.

Throughout the project the development process aimed to follow the process created by Ulrich and Eppinger *(6)*. However, some steps were not given as much time as others. One step that was largely ignored was the collection of customer statements. There were several reasons behind this decision. Firstly, it was not entirely clear who the customer actually was. This is visualised in *Figure 4.1*, showing that there could be multiple entities interested in the functionality of the product. Conducting interviews with people from each of these groups would take both time and effort and could not be justified in this project. Secondly, and perhaps more importantly, the goal was not to develop a new restraint system, it was to develop one specifically designed for the Nordic market. Still being a vehicle restraint system, it would share many of the qualities of already existing systems. Assa Abloy has a lot of experience with these types of products and have identified a great deal of customer needs that apply to all vehicle restraint systems. Using already identified needs meant that the development of the product could span over a longer period of time and, hopefully, yield a better result.

The concept generation part aimed to be as exhaustive as possible, considering all ideas no matter if they seemed good or bad initially. Later in the project this proved to be more valuable than was imagined. On several occasions when discussing the problem with colleagues and experts some solutions were proposed. During these discussions it was incredibly useful to already have explored the ideas and be able to inform the other part of their pros and cons. This is believed to have kept many meetings from discussing ideas that, while initially might have seemed good, were not feasible. The fact that almost none of the suggested ideas were unexplored also served as a reassurance that the development team had explored most realistic ideas and that the final concepts were, in fact, the best ones available.

The risk analysis was in this case only conducted at the very end of the project. Conducting the analysis this late meant that even if the design was shown to be unsafe there was little time to do anything about it. For the risk analysis to have any impact on design decisions it should have been utilised a lot earlier in the process, at the latest during the concurrent concept development stage. The safety of the concepts could then have been represented much more accurately during the concept evaluation.

One of the design requirements from Assa Abloy for this project was that no parts should be protruding from or recessed in the ground. However, this was unfortunately not communicated to the design team until the final concept selection in chapter 7.4.2. Had this requirement been introduced earlier many concepts could likely have been discarded in the first evaluation. Problems like these emphasise the need for clear communication between the design team and higher management. Something that was thought of in this project, though perhaps not enough.

Finally, with regards to concept generation it was somewhat surprising to note that good ideas seemed to come at an almost constant frequency throughout the process. One might be inclined to believe that the best ideas would be clustered in the beginning but that was not the case. Of the 106 total concepts the top 12 ideas were numbered at an average of 45,3, close to the middle of 53. In fact, of the first 10 ideas only one of them made it to the top 12. What this means will not be discussed further in this report, though it can be speculated upon. Could more concepts have been generated until there were no good ideas left? Or do all good ideas bring some bad ones along?

10 Conclusion

This project aimed to come up with a concept for a vehicle restraint system specifically designed for Nordic conditions. This mainly meant keeping the loading ground clear to not be in the way of snow ploughing. After exploring more than one hundred concept ideas, the proposed solution was a modification of an already existing Assa Abloy product. The results of these modifications were a hinged system that could be folded vertically, significantly reducing its footprint on the loading ground.

The project aimed to follow a product development process, with extra weight put on concept generation and evaluation. As the goal was to produce a concept rather than a final product it was paramount that the concept generation be as exhaustive as possible. This to ensure that the best solutions would be found in the evaluation process.

To continue the development of this project it is recommended that further risk analyses are conducted to investigate the real-world feasibility of a vertically folding system. On another note, folding vertically is only one way of clearing the loading ground and, though a horizontally folding system was investigated, it would be interesting to explore in what other ways the folding mechanism could function. The area under the dock houses is one of particular interest, as it is empty space that possibly could be used for storing the product during ploughing and cleaning of the loading ground.

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Appendix A Work Distribution and Time Plan

In accordance with the master thesis requirement, the following appendix contain the work distribution in the group as well as the time plan from the goal document and the time plan as it happened.

A.1 Work distribution

The work distribution in the team was balanced between the members near 50% - 50%. As the difference in background between the product development master and the technical design master is very similar in effect. The work that was not done as a team was done on a working separately and reviewing together basis.

The main differences between the group members are as follows:

Rasmus did:

- Product architecture
- Proof-reading

Teodor did:

- Illustrations and diagrams
- Simulations

A.2 Project Plan and outcome

Table A.1 Project plan.

Activity	Jan		Feb				Mar				Apr				May					Jun	
	W 4	W 5	W 6	W 7	W 8	W 9	W 10	W 11	W 12	W 13	W 14	W 15	W 16	W 17	W 18	W 19	W 20	W 21	W 22	W 23	W 24
Market research	■	■																			
Requirement management		■	■	■																	
Broad concept generation			■	■	■																
Broad concept evaluation					■																
In-depth concept generation						■	■	■	■												
In-depth concept evaluation								■	■												
Final design iterations										EASTER	■	■	■	■	■	■					
Prototyping											■	■	■	■	■	■					
Physical testing															■	■	■	■			
Presentation																			■	■	
ASSA ABLOY review						■													■	■	■
Peer review																			■	■	■
Report writing	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■		

Table A.2 Outcome.

Activity	Jan W 4	Jan W 5	Feb W 6	Feb W 7	Feb W 8	Feb W 9	Mar W 10	Mar W 11	Mar W 12	Mar W 13	Apr W 14	Apr W 15	Apr W 16	Apr W 17	May W 18	May W 19	May W 20	May W 21	May W 22	Jun W 23	Jun W 24
Identifying customer needs	■	■								EASTER											
Product specifications		■	■																		
Concept generation			■	■	■																
Narrowing down & Concept screening					■																
Concurrent engineering					■	■															
Concept scoring						■															
ASSA ABLOY review						■															
Product Architecture Design							■				■										
Sub-system Design							■	■	■		■	■	■								
Risk Analysis													■	■							
CAD model											■	■	■								
Prototype												■	■	■	■						
Presentation																		■	■		■
Peer review																			■	■	
Report writing				■	■	■	■	■	■		■	■	■	■	■	■	■	■			

Appendix B Concepts

B.1 Concept Tree Containing Concepts.

Table B.1 The complete table from which Table 6.1 were created.

Prevent Drive-away	Moment (torque)	Locking	Wheel	14. Loket
				35. Hjullås
				45. Handbromshandske
				23. Anakonda
				32. Auto-anakonda
				81. Hjulhuskudde
				82. Pinne i hjulet
				83. Hjulskralde
				84. Hjulchuck
				87. Hijacka elsystemet
				75. Klämma-däck-broms
			Drive shaft	71. Greppa drivaxeln
				85. Drivaxelklyka
				86. Drivaxelband-broms
		Unlocking		9. Frirull
				43. Hal mark
				88. Snurrblock
				94. Plåtmark
	Blocking (Compression)	Wheels		1. Tusen nålar
				7. Skivbarrikad
				8. (inte)Skivbarrikad
				5. Barrikad
				6. Banan-barrikad
				2. Tusen nålar i sidled
				18. Autolock
				26. Hål
				22. AR-2
				34. Rullande kil
				33. Tusen backar
				61. Följande kil
				62. Följande kil med rullor

			17. Stöttarm
			76. Grop med assistans
			77. Gasfjäderlås
			89. AR-2.2
		Front	44. Vägg framför
			78. Ballongblock
			79. Barblock
			90. Bom
		Undercarriage	3. Tusen nålar under hela
			80. Understolpe
			91. Pizza -barikad
	Holding (tension)	Wheels	11. Svängarm
			13. Myrbett
			36. Kanelbulle
			38. Armadillo
			42. Krypstock
			48. Autoklämma
			39. Arrestor-cable
			40. Magentiskt lås
			37. Hängklämma
			64. Skruvar i hjulet
			92. Fäljkrok
		Rear	46. Dragkrok
			53. Magnetisk gummikloss
			57. Jättemyra
			60. Manuell letande krok
			55. Kloss-lock
			50. Letande uks-lås
			59. Dörrlåskrok
			65. Vert-balk-klämma
			47. Bakgavellyftklo
			58. Leveler friktion
			93. Sugpropp
		Front	24. Förlängd fällbrygga
			25. Kranlås
			66. Skyddsmask
			95. Kort skyddsmask
			96. Halv jättemyra
			97. U-bom
		Undercarriage	49. Hjulaxelkrok
			4. Äggdelaren
			98. Kolyft
		Roof	28. Grytlappen

				30. Tak-leveler
		Sides		21. Fallbrygga
				29. Sido-leveler
				31. Väggklämmare
	Abstract/partial	Movement of mechanism		10. Sänglampan
				12. Skjutarm
				21. Carriage
				63. Teleskopiskt spårskydd
				19. Hulling
				99. Kör på market
				100. BGL skydd
				101. Nergrävd kuggstång
				103. Två sturrar
				105. Cykelkedja
				102. Rullande motstånd
				106. Garagestolpe
		Outside of the box	Small scale	72. Stoppa motorn
				69. Töm bränsletankarna
				67. Koppla bort lastbilen
				70. Ta av hjulet
				68. Lås ute chaufförerna
			Large scale	73. Moroten och Piskan
				74. Lots-docka
		Locating		51. Look-up-table för reg-plåt
				15. Lastcells-array
				16. Sista-hjulet-givare
				104. Dra åt
		Vertical forces		52. Ballong
				27. Lyft hela
				41. Magnetisk mark
				54. Pull-down-help
				56. Lastnät