DEGREE PROJECT

Improving Microwave Oven Safety in Truck Cabins

Preventing Projectiles on Crash/Brake

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Industrial Design Engineering, bachelor's level
2018

Luleå University of Technology
Department of Business Administration, Technology and Social Sciences

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2017

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Abstract

Large trucks may have an integrated microwave oven, or a driver may add one as a standalone solution, to allow heating food during long-haul transports. If a crash occurs with an item inside the oven, it may thrust against the door with such force that it opens from the inside. The goal of this thesis work is to develop a concept for a universally applicable solution that prevents flying parts from within the oven on a crash, as that presents a safety hazard for anyone inside the cabin.

The thesis work was conducted according to a stage gate process, which included four phases: Context, Ideation, Concept Development, and Concept Design. It includes interviews, company visits, literature searches, design methodology, concept comparisons and computer aided design.

The thesis work concludes with three concepts, all of which are locking solutions that are applied externally onto a microwave oven. They include a bolt latch, a solenoid lock, and a bolt latch integrated with the oven's door button. All solutions traverse the transition area between door and panel.

KEYWORDS: truck cabin safety, lorry safety, locking solution development, microwave oven locking solution

Sammanfattning

En del lastbilar har en integrerad mikrovågsugn, alternativt så kan en förare införskaffa en mikrovågsugn som en fristående lösning, för att tillåta uppvärmning av mat under långa transporter. Om en kollision inträffar med ett föremål inuti ugnen kan detta slungas mot ugnsdörren med en sådan kraft att den öppnas inifrån. Målet med examensarbetet är att utveckla ett koncept för en universell lösning som förhindrar att föremål kastas ut ur ugnen vid en krasch, eftersom det utgör en säkerhetsrisk för de som färdas i hytten.

Examensarbetet genomfördes enligt en stage-gate-process, som delats in i fyra faser: Kontext, Idegenerering, Konceptutveckling och Konceptdesign. Det inkluderar intervjuer, företagsbesök, litteratursökning, designmetodik, konceptjämförelser och datorstödd konstruktion.

Arbetet avslutas med tre konceptförslag som alla är låslösningar applicerade externt på en mikrovågsugn. Lösningarna består i: ett skjutlås, ett elektromagnetlås, och ett skjutlås som är integrerat i en mikrovågsugns dörrknapp. Samtliga lösningar behandlar övergångsområdet mellan dörr och panel.

NYCKELORD: Lastbilssäkerhet, Lastbilshytt säkerhet, låsfunktion utvecklingsarbete, mikrovågsugn låsfunktion

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1 Introduction

This report is written as a thesis at the Industrial Design Engineering BSc program at Luleå University of Technology. The thesis work is commissioned by ÅF, an engineering and consulting company for the energy, industrial, and infrastructure markets. It was conducted in the autumn of 2017, in Gothenburg, Sweden.

1.1 BACKGROUND

In 2015-2016, there were 62 453 registered trucks in Sweden. Their transport routes are both domestic and international. In total, more than three billion kilometers were covered by Swedish-registered lorries during 2015-2016. This distance was covered by over forty million transports, of which almost five hundred thousand were transports abroad (Berntsson & Söderbaum, 2017).

Truck driving categories include drayage, regional, pickup and delivery, owner-operator, and long haul (Trucking Job Finder, 2017). Long haul trucking can be defined as driving farther than 200-300 kilometers from the driver's home terminal (Complete School of Truck Transportation, 2014).

On national roads (in Sweden) approximately four million transports were long haul transports (Berntsson & Söderbaum, 2017). If transports abroad are also considered long haul transports, the number increases to about four and a half million transports.

Trucks designed for long haul transport often have an integrated microwave oven for heating food during transports. A crash or heavy brake can make an item inside the oven thrust against the oven door with such force that it opens from the inside. This presents a safety hazard for anyone traveling within the truck cabin and must therefore be prevented. Examples of microwave oven positions inside a truck cabin are presented in Figure 1.

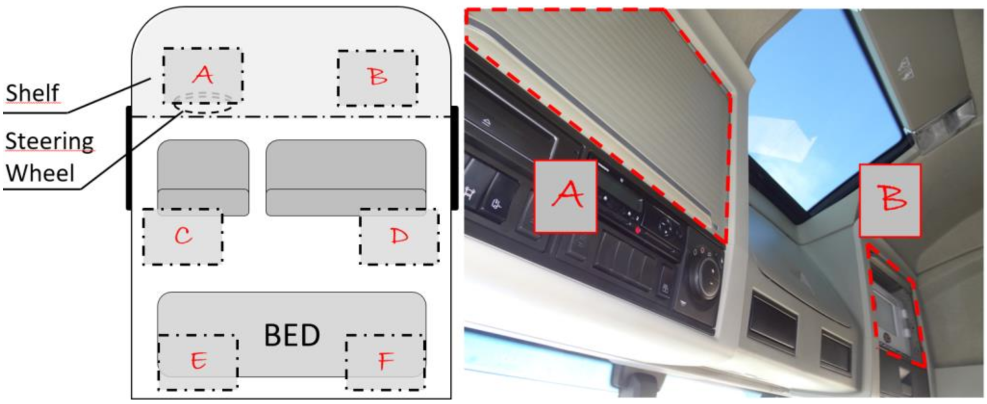


Figure 1, A-F are examples of microwave oven positions in a truck cabin. The right-side picture shows a microwave mounted in position B.

The integrated microwave oven is commonly placed behind a jalousie, or a shutter. During use in transport, however, there is no guarantee that the jalousie or shutter is closed. A human error can present an additional life-threatening element during a crash or heavy brake. This is incentive to develop an errorproof solution for preventing things falling out of the microwave oven. There are several microwave oven manufacturers that design ovens for use in truck cabins, and a solution should preferably be applicable across all or most available ovens. A developed solution may be applied by a truck driver, or by the microwave oven manufacturer company.

1.2 STAKEHOLDERS

Stakeholders include the microwave oven manufacturer, its operators, and sales team. The manufacturer's customers – truck manufacturers, haulage contractors, and truck drivers purchasing an oven are also stakeholders. Truck manufacturers are not only stakeholders in the sense that they install the oven, it also presents a hazard for a driver if a crash occurs and the microwave oven is not secure. Improving truck cabin safety by making the microwave oven more secure may increase scores such as the Euro NCAP safety score (if the microwave oven is a default option with the truck).

1.3 OBJECTIVE AND AIM

The **aim** of the thesis work is to improve truck cabin safety by decreasing risk of flying parts from a microwave oven during a crash/heavy brake – without impacting microwave oven usability.

The **goal** of the project is to develop a concept for preventing flying parts from within a microwave oven during a truck crash/brake. Concepts will be evaluated and compared. A recommended concept will be selected and presented, together with its alternatives, using a 3D-model.

To achieve the goal of the thesis work, the following **guiding questions** are used:

- Q1. How and when are microwave ovens in truck cabins used?
- Q2. How can items in a truck cabin microwave oven be prevented from falling out during a crash/hard brake?
- Q3. How will a proposed solution affect usability of the microwave oven?

1.4 PROJECT SCOPE

The project scope is to develop a concept for preventing projectiles from inside an integrated microwave oven during a truck crash.

Requirements for the solution are formulated together with client, and include:

- R1. None or minor impact on how the microwave oven is being used today
- R2. No protruding parts or protruding parts designed in compliance with AIS 047, FMVSS 201 and ECE 21
- R3. A mechanical solution
- R4. No detaching parts on brake or crash
- R5. The solution must bear everyday use of the integrated oven without impacting its function on a crash/brake
- R6. No hindering the installing of the integrated microwave oven
- R7. Applicable on the most common button-to-open microwaves

(exceptions
are microwave ovens with oddities such as sloped buttons)

R8. Applicable regardless of the microwave oven's location inside the cabin

This project is limited to:

L1. Microwaves with an exposed front
L2. Developing a concept (not a product)
L3. Commercial applications of microwave ovens for integration in trucks
L4. No replacing or major reconstruction of microwave oven design

1.5 THESIS OUTLINE

Chapter 1 introduces the thesis work, its scope and the incentive for it to exist. Chapter 2 puts the thesis work into context. It provides examples of how an integrated microwave oven may look today, and similar environments and potentially interesting solutions in other areas. Chapter 3 provides the theoretical framework that is the foundation for the thesis work. Chapter 4 provides the methods used. The results are presented in chapter 5. And finally, chapter 6 discusses the result of the thesis work, its methods, positions the result and suggests areas for further work.

2 Context

Microwave ovens are a common commodity in trucks used for long haul transports. During truck parking visits, it became apparent that in contrast, trucks used for medium haul or short haul transports seldom have integrated microwave ovens.

In Sweden, the daily driving time for long haul truck drivers may not exceed 9 hours. However, it may be extended to 10 hours twice per calendar week. The maximum driving time per week is 56 hours. During two consecutive weeks, driving time may be maximum 90 hours. After driving continuously for 4 hours and 30 minutes, the driver should take a break of at least 45 minutes, or a split break of 15 and 30 minutes. After an approved break, and once the driver resumes driving, a new driving period starts (Transportstyrelsen, 2017).

Microwave oven integration in truck cabins have introduced a big change for truck drivers across the globe. Where they previously had to stop at designated truck stops or restaurants along a transport route, they now have the option to rapidly cook or heat prepared food.

In trucks without integrated microwave oven, a driver has the option to add one to improve his/her standard of living. One such example is presented in Figure 4.

Four truck driver interviews yielded this information:

- The microwave oven is seldom in use during transport. It is mostly in use when the truck is stationary during breaks.
- The microwave oven is mainly being used for heating lunch boxes of ~400 grams (estimated by drivers). An example is presented in Figure 2
- The microwave oven is occasionally being used for cooking eggs, potatoes, heating water and heating coffee

Figure 2, a lunchbox brought by a truck driver

It was learned that an integrated microwave oven is sometimes (if seldom) in use during transport. It may be used for heating lunch boxes and for cooking and as such may contain heavy items. The main use of the microwave oven for all truck drivers was heating lunch boxes. One truck driver also spoke of an array of plastic utensils that allow for cooking with a microwave oven, for example boiling potatoes or eggs. There are also items that allow for frying in the microwave oven. Examples of such utensils are presented in Figure 3, these can weigh up to 1,3 kgs empty.

Figure 3, left: microwave oven grill. Right: pressure cooker for microwave oven use. Source: https://www.coolstuff.se

2.1 PLACEMENT OF MICROWAVE OVENS

In today's truck cabins a microwave oven may be contained behind a jalousie, in a box, or with an exposed front. There is no guarantee that the jalousie or box will be closed when the oven is in use.

A standalone microwave oven that is used in a truck cabin is presented in Figure 4. It has a manual locking solution for safety reasons. The truck driver in question was keeping it inside a box, and would lift it out before using it.

Figure 4, standalone microwave oven for truck cabin use.

Integrated microwave ovens are commonly kept behind a jalousie or shutter. This is illustrated with a collage in Figure 5.

Figure 5, a collage of truck cabin integrated microwave ovens kept behind a jalousie or shutter.

2.2 BENCHMARKING

During benchmarking, similar environments with integrated ovens were researched, along with interesting, unique, or common locking solutions.

2.2.1 Similar environments with integrated ovens

Other environments with integrated ovens include aircrafts, marine vehicles, and trains. Ovens observed in a Boeing 747 and in a commercial train are presented in Figure 6.

Figure 6. Left: an integrated oven in a Boeing 747 commercial aircraft. Right: two microwave ovens on a commercial train in Sweden.

A pilot with SAS was interviewed. He later took the pictures on the commercial airplane. The pictures on the train were captured on a train between Copenhagen and Gothenburg. The Boeing 747 integrated oven in Figure 6 has a rotating latch which applies a lock. If left unlocked, the oven cannot be used. By contrast, the microwave ovens on the commercial train did not appear to have any visible locking solutions applied. When the train company was contacted, no information was uncovered about an additional locking solution.

For naval solutions, Loipart (a company that, among other things, specialize in kitchen appliances on marine vehicles) was contacted. Loipart provide many different microwave oven products. None of the ovens open by a button, which put them outside the scope of this thesis work (Loipart, 2017). They may still serve as a source of inspiration. There are several manually applied locks. The most common solutions are heavy machinery with strong doors. The doors often open by pulling a handle. By contrast, microwaves in a truck environment commonly open by a button.

Figure 7, two ovens for naval use. Source: http://www.loipart.com/

2.2.2 Locking solutions researched

An inventory of some locking solutions is presented in Table 1. An active locking solution is (in this thesis work) defined as having to be activated, for instance by electrical impulse as is the case with the active element described for seatbelts (Appendix 1). A passive locking solution is defined as remaining in its locked position after being enabled.

The locking solutions presented in table 1 are further described in Appendix 1.

The solutions featured in Table 1 frequently appeared during benchmarking research. They are examples of locking solutions and were selected because they had interesting or unique properties.

Table 1, locking solutions researched during benchmarking

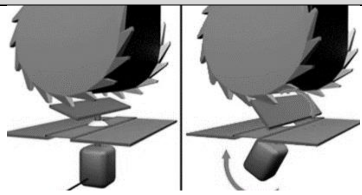
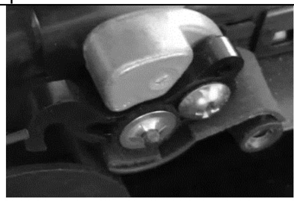
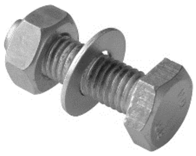
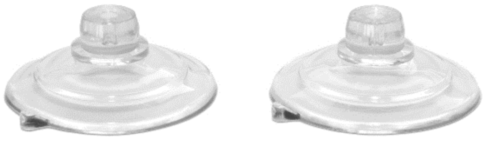
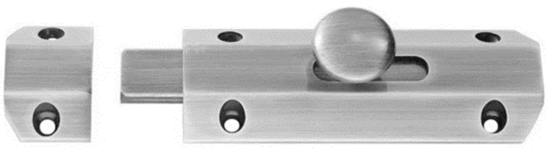
Locking solutions	Illustration	Passive/Active
Seatbelt	 Figure 8, the passive element of a seat belt mechanism	Passive/Active
Momentum-based	 Figure 9, a momentum-based locking mechanism in a honda civic	Active
Brake disks	 Figure 10, brake disks	Active
Screw/Nuts	 Figure 11, a nut, screw, and spacer	Passive
Suction	 Figure 12, suction cups	Passive/Active
Ethernet cable	 Figure 13, the head of an ethernet cable	Passive
Excenter lock	 Figure 14, an excenter lock	Passive
Slide bolt	 Figure 15, a slide bolt lock	Passive

Table 1 provide many different types of locking mechanisms. They include those based on friction, vacuum resistance, momentum induced, movement prevention by blocking, and translation of force.

2.3 DESIGN SPECIFICATION

Requirements and limitations are listed in the introduction chapter. They are treated according to each respective number.

Table 2, guiding questions, requirements and limitations

Category	List
Requirements	1. None or minor impact on how the microwave oven is being used today 2. No protruding parts or protruding parts designed in compliance with AIS 047, FMVSS 201 and ECE 21 3. A mechanical solution 4. No detaching parts on brake or crash 5. The solution must bear everyday use of the integrated oven without impacting its (the solution concept's) function on a crash/brake 6. No hindering the installing of the integrated microwave oven 7. Applicable on most button-to-open microwaves 8. Applicable regardless of the microwave oven's location inside the cabin
Limitations	1. Microwaves with an exposed front 2. Developing a concept 3. Commercial applications of microwave ovens for integration in trucks.

Requirement 1 implies that how a microwave oven is currently used must be impacted as little as possible. This means that modifications to buttons, turning knobs and any panel should be avoided as much as possible, and any modifications or applications near those instruments should be as unintrusive as possible. It also implies that functions should be left unaltered if possible, an example of a function where this applies is that pressing the open-button opens the oven door.

A mechanical solution implies that the solution works by translation of forces, which means that an external force (such as pushing a button, or pulling a lever) activates the mechanism, and translation of forces allows it to perform its intended function. In the context of this thesis work, it means that no electrical appliances should be necessary for the solution to work as intended.

The solution must be designed with such integrity that there is no risk of flying parts from it in case of a crash or heavy brake (which requires future validation).

To make sure that a solution can bear everyday use, concept design suggestions must be sensible (but will require future validation regardless)

The installing of the microwave oven should not be hindered, by design. For instance, by avoiding concept designs that restrict an operators hand movement around the microwave oven.

The solution should not include existing details that are usually dissimilar between microwave ovens, such as internal mechanisms for opening the door (unless the solution applies despite these differences).

The last requirement implies that the solution musnt't have any reliabilities with regards to its position, such as the need to face in a certain direction, or proximity to an outlet.

3 Theoretical framework

The theoretical framework for this thesis work is based on the guiding questions under chapter 1. It supports the methodology for the development process, and provides relevance of the thesis work to Industrial Design Engineering. The theoretical framework is illustrated in Figure 16.

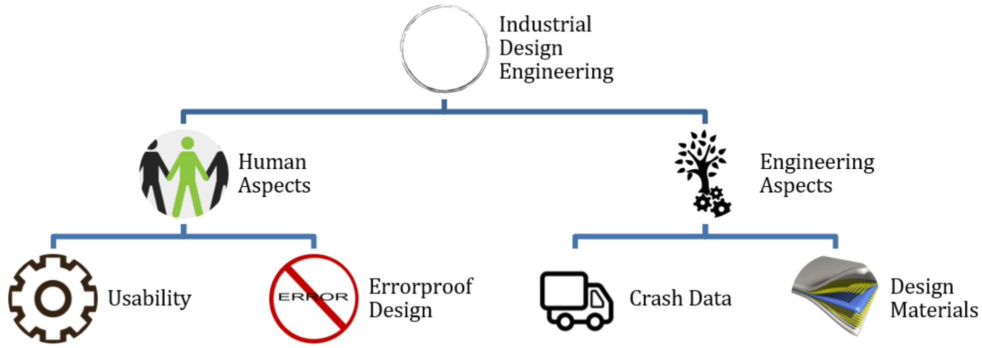


Figure 16, the theoretical framework and its components.

Industrial design engineering is a means of developing products, services, environments and systems. Its purpose is to create sustainable solutions based on human needs and conditions (Luleå University of Technology, 2017).

A definition of industrial design by World Design Association is as follows:

> *"Industrial Design is a strategic problem-solving process that drives innovation, builds business success, and leads to a better quality of life through innovative products, systems, services, and experiences. Industrial Design bridges the gap between what is and what's possible. It is a trans-disciplinary profession that harnesses creativity to resolve problems and co-create solutions with the intent of making a product, system, service, experience or a business, better. At its heart, Industrial Design provides a more optimistic way of looking at the future by reframing problems as opportunities. It links innovation, technology, research, business, and customers to provide new value and competitive advantage across economic, social, and environmental spheres." (World Design Organization, 2018)*

Industrial design engineering solutions are technically functional, attractively designed, ergonomic and user-friendly. Combining engineering skills with industrial design creates the opportunity to develop innovative products and services based on the needs of people, the environment and industry. Industrial design engineering provides an overall perspective on product development and knowledge to combine design with materials, mechanics and IT services to create better solutions for the future (Chalmers University of Technology, 2017).

3.1HUMAN ASPECTS

This chapter is divided by two ergonomics aspects that belong to the framework of the thesis work. The first subchapter concerns usability. The second is about preventing failure by human error, or errorproofing.

3.1.1 Usability

Usability is a quality attribute that indicates how easy a user interface is to use. It refers to the quality of a user's experience during interaction with products or systems (examples of systems are websites and applications) (Usability.gov, 2017). Usability may be associated with matching products and systems with user needs and requirements (Usability Net, 2017). The word "usability" also refers to methods, the aim of which is to simplify how something is used, that are applied during the design process (Nielsen, 2012). Usability can be designed by five quality components (International Organization for Standardization, 2017):

- Learnability: How easy it is for users to perform simple tasks the first time they encounter the design.
- Efficiency: When a user is familiar with a design, how fast can they perform its task regularly?
- Memorability: If a user hasn't interacted with a design for some time, how easily can they reestablish proficiency?
- Errors: Are errors present? How many, how severe, and how easily can these errors be recovered from?
- Satisfaction: How pleasant is the design to use?

Together with usability, it is also convenient to mention utility, which is defined as features that are required. This is mentioned because it takes precedence over usability, which means that if a required function and a function that improves usability are in conflict, it is likely that a designer will choose utility over usability (Nielsen, 2012).

To assess a concept's affect on usability of an already existing product, one must identify how the product is currently used. In the context of this thesis work, the microwave oven is opened by engaging the button which opens the door. Knowing this, one must evaluate the concept design to determine if it has potential to change how the microwave oven is used. In simpler words: how is the microwave oven used today, and might the suggested concept affect how it is used?

3.1.2 Errorproof design

In a design process, designers also design user activity, which occur together with the product (Stanton & Baber, 1998).

Errorproof design requires a designer to identify (potential) error behavior by any user, and prevent it by design. This kind of design process is sometimes called Design with Intent, or DwI (Lockton, Harrison, & Stanton, 2009). To use DwI in this context a designer must identify what constitutes error behavior. In a development process a designer may have to consult someone with extended knowledge in whichever field the designed product belongs to, to determine error behavior. Or, an error behavior is already identified, and the purpose of the design process is to design a solution/elimination of this behavior.

One example of errorproofing, given in Lockton, Harrison & Baber's editorial for the Applied Ergonomics journal 2009, is an ATM cash machine not dispensing cash until the card has been removed from the machine. This way, one cannot forget to bring the card without also not receiving the cash withdrawal (Lockton, Harrison, & Stanton, 2009). This is a way of ensuring that a mistake cannot be made, and is an example of design to eliminate error behavior.

There are examples of errorproof design solutions in today's microwave ovens, and in ovens for use in commercial airplanes. For airplanes, the oven cannot be activated unless the oven door is locked (which was mentioned in chapter 2). Regular microwave ovens usually cannot be activated unless the door is closed. Both are examples of errorproof design.

3.2 ENGINEERING ASPECTS

The engineering aspects are subchaptered by legal requirements, crash data and design materials.

3.2.1 Legal Requirements

AIS 047, FMVSS 201, and ECE 21 are safety standards for interior fittings in automotive vehicles. They relate to this thesis work by specifying requirements that apply to shelves, switches, pull-knobs, and other similar objects:

- Switches, pull-knobs, and other similar objects made of rigid material, shall have cross-sectional area of not less than 2 cm measured 2.5 mm from the furthest projecting point, and shall have rounded edges with a radius of curvature of not less than 2.5 mm.
- Shelves, including luggage racks and other similar items, shall be so designed and constructed that the part facing the vehicle shall present a surface not less than 25 mm high with edges rounded to a radius of curvature of not less than 3.2 mm and the supports in no case have protruding edges.

3.2.2 Crash data

Very few studies have reported on crash severity of crashes which includes heavy trucks (Holmqvist, 2016). One study found that 64% of the studied collisions which involved two heavy trucks were at closing speed (speed of approach) of up to 50 km/h (Gwehenberger, Langwieder, Bromann, & Zipfel, 2002). Another study reported that 72% of all studied cases for the same criteria had a velocity difference of up to 30 km/h, with 21-30 km/h being the most common difference (Simon, Botto, & Paulhet, 2001).

In all accidents which involve heavy trucks, collisions with other vehicles (regardless of subsequent rollover), single vehicle accidents resulting in rollover, or collision with roadside objects, are most frequent in occurance. 24% to 54% of heavy truck accidents result in rollover (Campbell & Sullivan, 1991; Zinser & Hafner, 2004; Gwehenberger, Langwieder, Bromann, & Zipfel, 2002; Simon, Botto, & Paulhet, 2001).

In one study, eight heavy truck front-to-trailer sled tests were designed and performed by AB Volvo in Sweden. The impact velocity was set to 30 km/h, with a resulting average peak acceleration of 289 m/s^2 (Holmqvist, 2016).

3.2.3 Design Materials

Table 3 provides data on steel that is commonly used for bolts and wedges. It also provides an alternative construction steel which is corrosion resistant (Sundström, 2013).

Table 3, data for steel used in bolts, wedges and general corrosive resistant construction.

Steel type	Characteristics	Shear breaking limit (MPa)	Density kg/m^3
141650	Toughened, commonly used for bolts and wedges	645	7780
2344-02	Solution heat-treated, stainless steel. Commonly used for construction with high corrosion resistance	367,5	8000

Polymers are commonly brittle and strong, or soft and tough, as indicated in Figure 17.

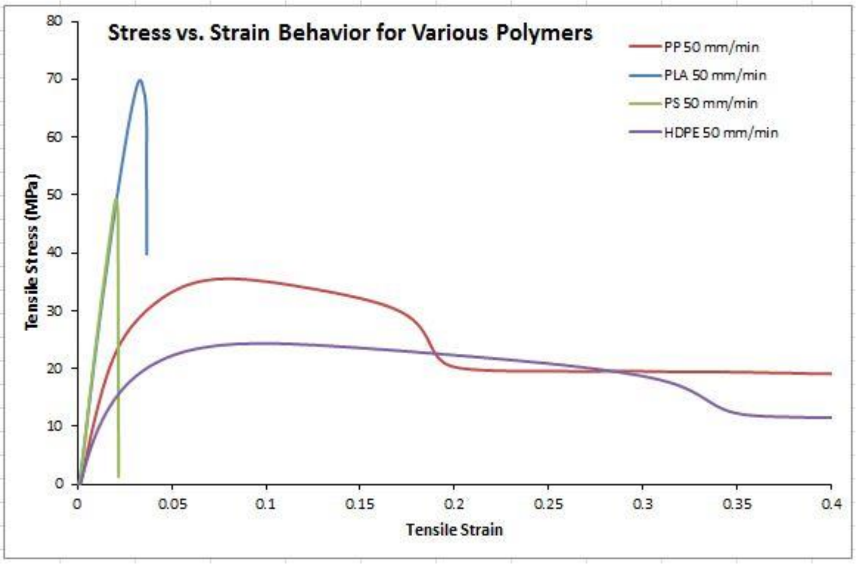


Figure 17, stress-strain behaviour of four common polymers.

Steel is a common design material in critical construction components that are subject to heavy strain (for instance in a vehicle crash).

4 Method and Implementation

An organized and structured way to work is important for a concept (and product) development process. This thesis has been treated as a project. A project is defined as having a set goal, determined time frame, planned resources and a temporary organization. It is commonly split into pilot study, planning, implementation, and conclusion (Tonnquist, 2016). The temporary organization in this case consists of the thesis student, the tutors, and the client. This thesis work was initiated by planning and divided into four phases: Context, Ideation, Concept Development, and Concept Design. Each phase was further broken down using a WBS (Work Brakedown Structure) which is illustrated in Figure 18. (Tonnquist, 2016; Buzan, 1980):

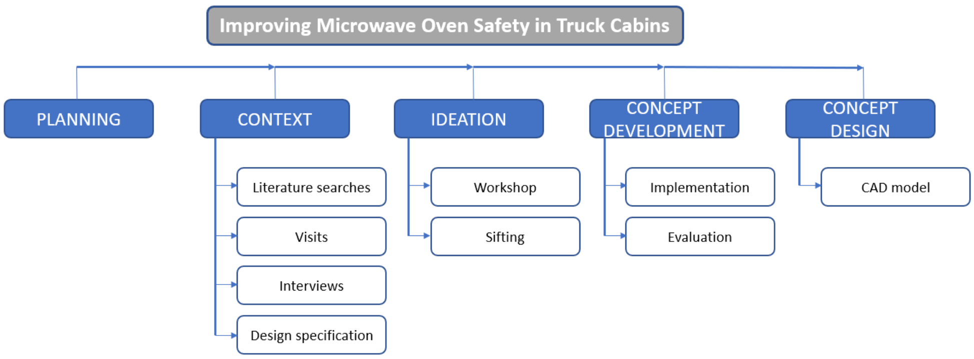


Figure 18, Work Brakedown Structure.

4.1 PLANNING

The project was planned with Gantt schedule by week (Figure 19) and by day, in excel. There was also a separate tab for each phase of the project with notes.

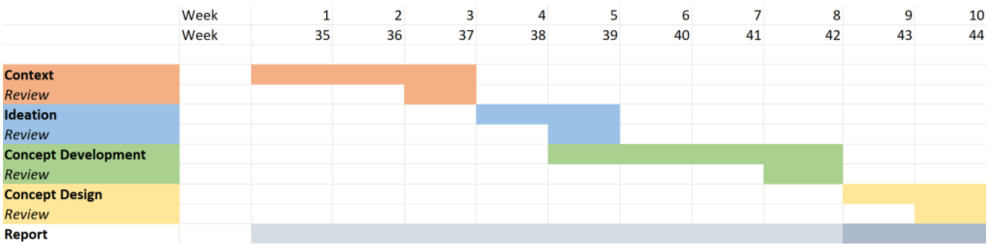


Figure 19, project planning by week.

4.2 CONTEXT

Table 2 is a visualization of how the thesis work was put into context:

Table 4, putting the thesis work into context by category with actions in each respective category.

Category	Actions
Solutions to potentially similar problems	• Online searches • Visit to Autoliv
Examining truck cabin (with microwave oven) environment	• Online searches • Visits to truck parkings • Visit to Volvo Trucks sales location
Examining similar environments with microwave ovens or regular ovens	• Online searches • Train visits • Meeting with commercial airline pilot • Telephone contact with boat/airplane companies

4.2.1 Literature searches

Literature searches were conducted with regards to the guiding questions of the thesis work:

Q1. How and when are microwave ovens in truck cabins used?
Q2. How can items in a truck cabin microwave oven be prevented from falling out during a crash/hard brake?
Q3. How will a proposed solution affect usability of the microwave oven?

Literature searches with regards to how microwave ovens in truck cabins are used focused around the truck drivers eating habits, with search parameters added to zone in on microwave oven use in a truck cabin. These searches yielded no results.

Literature searches with regards to how items in a truck cabin microwave oven can be prevented from falling out during a crash/hard brake involved researching locking mechanisms, prevention methods for shutters opening and self-locking mechanisms. It also involved researching solutions to similar problems in aircrafts, boats and trains. The results of these searches are mostly presented in the Benchmarking chapter.

Regular google searches were conducted to learn about commonly used solutions for locking mechanisms

Literature searches with regards to developing an errorproof solution initially focused around the poka yoke concept of preventing human error during manufacturing processes. By reference, it ventured into the Design with Intent method.

Most search strings are detailed in Table 5.

Table 5, search strings and their results.

Q#	Main search string	Additional search terms	Google Scholar	Web of Science	PubMed	Relevant results
1	(”truck driver” OR (truck AND driver*) OR trucker OR (lorry AND driver) OR “lorry driver” OR (“heavy duty vehicle” AND driver) OR (“long haul” AND driver))	AND food AND microwave	9010	0	0	0
		AND eating habits	46 300	10	11	0
		AND eating habits AND microwave	9310	0	0	0
		AND "microwave oven"	1590	0	0	0
2	“locking mechanism”	AND safety	13 500	39	-	0
		AND safety AND "microwave oven"	57	0	-	0
		AND passive	7040	57	-	0
	self locking mechanism		17 900	34	-	0
	prevent* opening AND crash		-	195	-	0
	retard* AND activat* AND prevent* AND fall*		-	2	-	1
	prevent* AND shutter AND open*		-	58	-	0
	Usability	AND definition	30 700	-	-	3
	“poka yoke” AND lock		782	0	-	3
	Patterns for influencing behavior through design		-	882	-	1
3	(Aeroplane* OR airplane* OR “air plane*” OR aircraft* OR “air craft*”) AND oven*		21 800	128	-	0
	(ship* OR *boat* OR yacht* OR frigate* OR galleon* OR submarine*) AND oven*		33 600	110	-	0
	(train* AND micro*) AND oven*		18 700	106	-	0

4.2.2 Visits

A visit to Autoliv was conducted for elaborating on an interesting locking mechanism which is present in honda civic dashboard compartments as well as in seat belt assembly boxes, introduced in chapter two and described in appendix 1. Autoliv is a car safety developer, researcher and manufacturing company.

A visit to Volvo Trucks sales location was conducted for looking at trucks which have microwave ovens in the cabin. Pictures from within a truck cabin are presented in chapter two.

Truck transportation companies including DHL, GLC, and Schenker were also visited spontaneously, but none provided contact information of any truck drivers. Instead, truck drivers were spoken with on truck parking visits.

4.2.3 Interviews

In method theory, it is distinguished between quantitative method and qualitative method. The former often contains the collection of a variety of data and an analysis with statistical methods, while the latter often means, for example, interviews or participatory observation (Hansson, 2007). Since this concept focuses on truck driver experiences, interviews were chosen as a qualitative method of research.

Visits to truck parkings were conducted twice. In total, four truck drivers were interviewed. Two initially, and two additionally. Two of the drivers had microwave ovens integrated with their trucks, the other two had installed custom microwave ovens. An example of a manual locking mechanism in one microwave oven belonging to a driver is presented in chapter two.

Examples of questions asked are:

- When is the microwave oven in use?
    - Is it used during driving?
- What is the microwave oven used for?
- What do your lunch boxes weigh, and what do they look like?

The first driver uses the microwave oven for heating lunch boxes, coffee, and water. It is also used for cooking things, such as eggs and potatoes. The driver also spoke of using the oven for cooking in general, by using utensils that allow for frying and otherwise cooking food. These utensils are commonly available. He does not commonly use the microwave oven while driving, but says that he sometimes leaves things inside it (while driving).

The second driver only uses his microwave oven for heating lunch boxes. He mostly brings his lunch boxes from home, but sometimes buy factory made lunch boxes from stores along the transport route. He occasionally uses the microwave oven while driving.

The third and fourth drivers provided the same information as the first two. At this point, the information gained from these interviews proved saturated, and no further interviews were conducted.

4.2.4 Design Specification

A design specification was created based on the requirements introduced in chapter 1. In it, each requirement is explained in further detail to provide an idea of how it can be solved as the concept development process proceeds.

4.3 IDEATION

The ideation phase consisted of generating ideas by an ideation workshop, and subsequent sifting and sorting/combining of the ideas.

4.3.1 Workshop

A workshop was conducted during the ideation phase to provide ideas. The selected group invited to the workshop consisted of ten people (men and women between ages 25-28) – engineers in materials science, computer science, industrial design and social science students and graduates. Since the ideation phase intends to introduce a wide array of ideas, diversity withing the workshop group was necessary and desired.

The workshop process selected was brainstorming, discussion, and derivative ideas, because all three methods were appropriate for the number of people and the methods fit well in the workshop time frame (Johannesson, Persson, & Pettersson, 2013). The methods chosen also work well together, because they can build upon one another (but do not have to).

The brainstorming was divided into five phases (Johannesson, Persson, & Pettersson, 2013):

1. Initial brainstorming ideation (5-10 minutes)
2. Silence/break (2 minutes)
3. Main brainstorming ideation (5-10 minutes)
4. Silence/break (2 minutes)
5. Closing brainstorming (5-10 minutes)

The phases serve the following functions: 1. produce ordinary ideas, 2. relax the brain, 3. the "larger brain" is activated widening the scope of ideas generated, 4. relax the brain, 5. unusual ideas emerge.

Each individual idea was written/sketched on a post-it note. The idea-post-it note was then placed in the center of a table. If lacking ideas, one was encouraged to build off other ideas from the center of the table, or to pick ideas from the center of the table at random, to inspire additional ideas.All ideas were later presented to the group and discussed, generating further ideas. Finally, information from the context phase was introduced to inspire ideas derived from solutions to similar problems in other environments.

Figure 20, the idea notes generated from the workshop.

4.3.2 Sifting

After the workshop, all ideas were graded by creativity and implementability using a 2-by-2 matrix (Kreativitetsskolan, 2012). This was done subjectively by the thesis student. The reasonable ideas were categorized by dynamic and static solution ideas, then further subcategorized by momentum-based ideas (category 1), external solutions (category 2), and internal solutions (category 3). If possible and beneficial, ideas in the same category were combined.

4.4 CONCEPT DEVELOPMENT

The concept development phase is divided by theoretical implementation of a category into/onto a microwave oven, and evaluation of the further developed concepts.

4.4.1 Implementation

All categories were developed as single, separate concepts, which were labeled concepts 1- (**The Weight**), 2- (**The Bolt**), and 3 (**The Modifier**), according to the respective category number. The concepts were combinations of ideas, or the ideas judged most favourably with convenient elements added from other ideas in the same category. Each concept treated different areas of the microwave oven.

When evaluating The Modifier for integrating internal solution ideas into a microwave oven, it became apparent that a concept based on this category was not applicable, so the category was discarded.

4.4.2 Evaluation

The concepts were further evaluated with respect to ease of implementation, cost of implementation, usability impact, development cost, and reliability. These criteria derive from problem specification, guiding questions, and per request by client. The evaluation was done using a Pugh's Matrix (Pugh, 1990). It is an instrument for comparing concepts against a baseline (Burge, 2009), and relies on a series of pairwise comparisons. One concept acts as a baseline against which other concepts are compared.

The Pugh's Matrix is suitable as method when considering two concepts. If more concepts were considered the Method of Pairwise Comparison would have been a better choice, as it compares each concept against every other. Thus, the total score would be based on comparisons between all, rather than based on each concept against a baseline concept (Center of Academic Success, u.d.; Burge, 2009). In the case of two concepts being compared, Pugh's Matrix and the Method of Pairwise Comparisons provide the same score ranking.

In Pugh's Matrix, each concept is scored against a criterion in comparison with the baseline concept according to:

+ = better
0 = equal
- = worse

Each criterion may also carry a weight depending on its importance. In this thesis work, a simple version without weights is used (only two concepts were compared, and discussion with client revealed that one concept excelled with regards to all criteria but one, and that criterion was not more important than all others). The net worth shows how a concept performs compared with the baseline concept. A positive net worth means that the concept "won" against the baseline. It is recommended to use the comparison by Pugh's Matrix as an indication, but to apply common sense and make an authority decision (Burge, 2009; Johannesson, Persson, & Pettersson, 2013). An example of how Pugh's Matrix could look is presented in Table 6, example of Pugh's Matrix.Table 6, where *Alternative concept 1* is the clear winner.

Table 6, example of Pugh's Matrix.

Criteria	Optional importance weighting	Baseline concept	Alternative concept 1	Alternative concept 2
Effectiveness	5	0	+	-
Availability of resources	4	0	+	+
Support from business	3	0	-	-
Long term benefit	2	0	0	0
SUM		0	6	-4

4.5 CONCEPT DESIGN

Design suggestions for the concepts were created and presented with CAD, using CATIA V5 as a tool.

4.5.1 CAD model

An advantage of CAD over traditional sketches is that it puts the solution in its context, and provides an easy-to-interpret visualization of the concept's dimensions. In this thesis work, it shows how a concept might look if applied to a microwave oven, which allows for identifying construction problems and subsequent adjustments to the concept.

Concept 2 was further developed with regards to the requirements and guiding questions introduced in chapter 1. Once designed in further detail, concerns were raised with regards to the validity of its mechanism. As a result, two additional concepts were introduced, referred to as concepts 4- (**The Double**) and 5 (**The Solenoid**). They were designed to behave similarly to concept 2, but with more reliable solution mechanisms (if less in accordance with the requirements).

4.6 METHOD DISCUSSION

Qualitative and quantitative methods were distinguished between. The difference between qualitative and quantitative research lies in the interpretation of the data. Quantitative research is often quantified using values based on the data collected. In the context of this thesis work, a Pugh's Matrix is a qualitative technique which ranks how concepts perform against some criteria. Qualitative data interpretation was also used for analyzing the experiences expressed by truck drivers in the interviews conducted. This thesis work exclusively uses qualitative research data, but further work would include quantitative research data. Examples of what this could be are: forces applied to a microwave door with an item inside the microwave oven, actuation forces for door-buttons, and return forces for door buttons. Both research method categories are required for a successful product development process, because the analysis of qualitative data, as explained above, provide results based on opinions and experiences (like interviews or Pugh's Matrix), while the analysis of quantitative data provides reliable results based on many data samples under similar conditions (for instance measurements of button actuation forces).

5 Results

This chapter presents the results from each phase. The results from the ideation- and concept development phases converge and are the foundations of the final concept designs in the concept design phase.

5.1 IDEATION

The ideation workshop resulted in 41 post-it notes with ideas. The first sifting is presented in Figure 21.

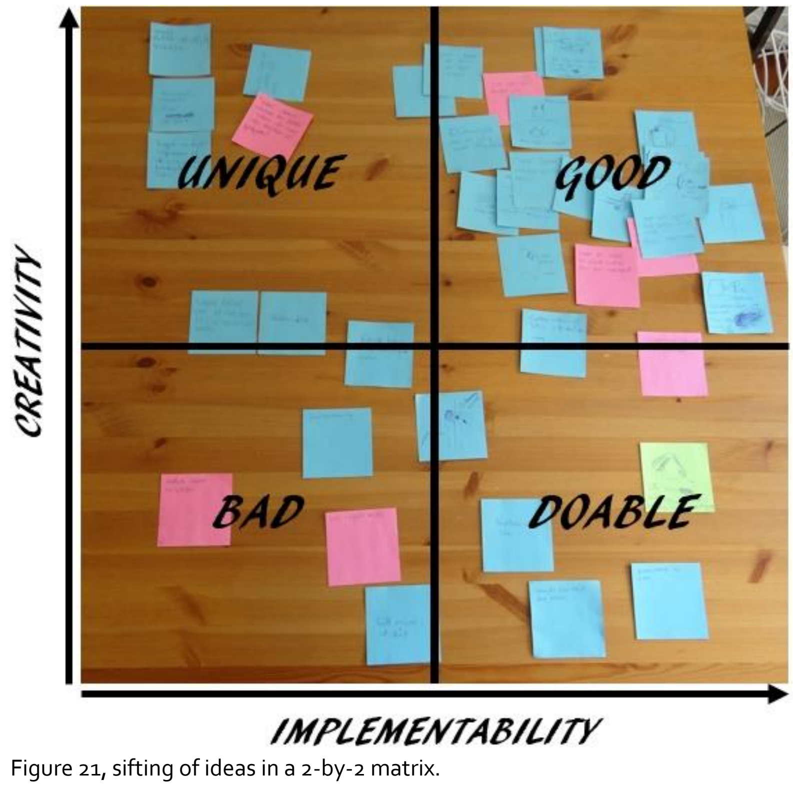


Figure 21, sifting of ideas in a 2-by-2 matrix.

A solution was judged favourably with regards to implementation if:

- Obviously good integrity
- Potentially easily implementable

A solution was judged favourably with regards to creativity if:

- Outside the box thinking
- Unique

Implementation and creativity were both continuously compared between ideas, so ideas were rearranged until all were placed in a subjectively reasonable position according to the criteria (and eachother).

The subsequent categorization of ideas is presented in Figure 22.

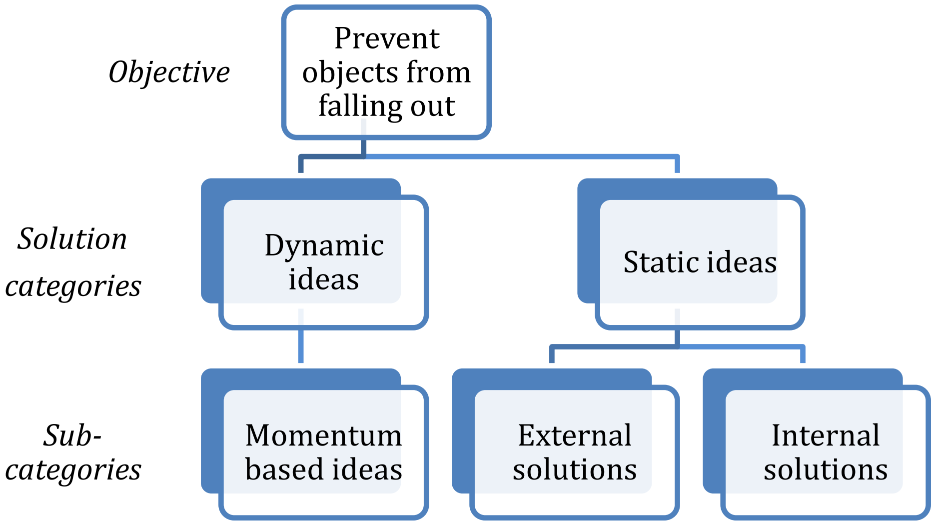


Figure 22, categorization of ideas.

Due to the project scope (only the front is exposed, mechanical solution etc.), and after deliberation with client, all the chosen ideas happened to center on the area near the panel, button, and door, indicated in Figure 23.

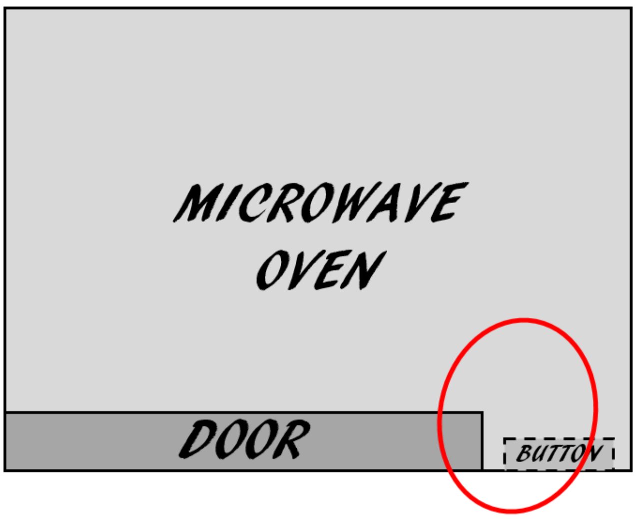


Figure 23, the area of the microwave oven that all approved ideas centered on, perspective from above the oven.

5.2 CONCEPT DEVELOPMENT

This chapter is divided into subchapters by each concept category.

5.2.1 Concept 1 – The Weight

The momentum-based solution category (category 1) was developed as a single concept, which was a result of combinations of ideas that survived the sifting process. It involves a weight translating its momentum during a crash to block the door from opening. The concept fits between the door of the microwave oven and the side of its panel according to Figure 24.

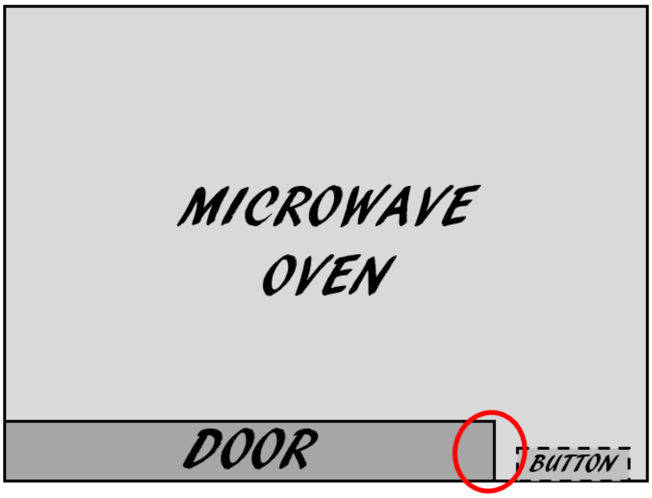


Figure 24, the area of implementation in the momentum-based category (concept 1).

The general idea is that a weight moving with the same speed as the truck (and the microwave oven) can use its momentum to force a lock in place when a crash or heavy brake occurs. Figure 25 is seen from the perspective in Figure 24. a) depicts the position of a weight and latch before a crash. b) depicts the movement of the weight and latch as the crash or brake begins, and c) depicts the latch in its destination.

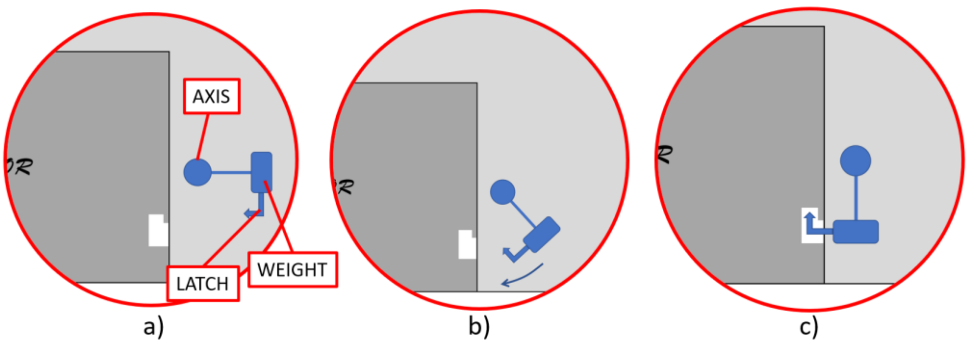


Figure 25, a momentum-based locking solution mechanism.

To suggest that the lock could be secure before an object inside the microwave oven could force the door open, a series of simple calculations were performed:

Figure 26 illustrates a momentum-based idea for a locking solution. A weight is free to rotate around an axis, and has a latch on one end. 90° from the center of the weight is the receiver for the latch (with the width *d,* according to Figure 26. In the thesis work context, the receiver would be in the microwave oven door, and the weight would rotate inside the base of the microwave oven – in the area indicated in Figure 25. For the following calculations, friction is not considered, and the speed is assumed to be constant – which should be accurate considering that the weight is traveling a very short distance. It is also assumed that the truck comes to an immediate stop.

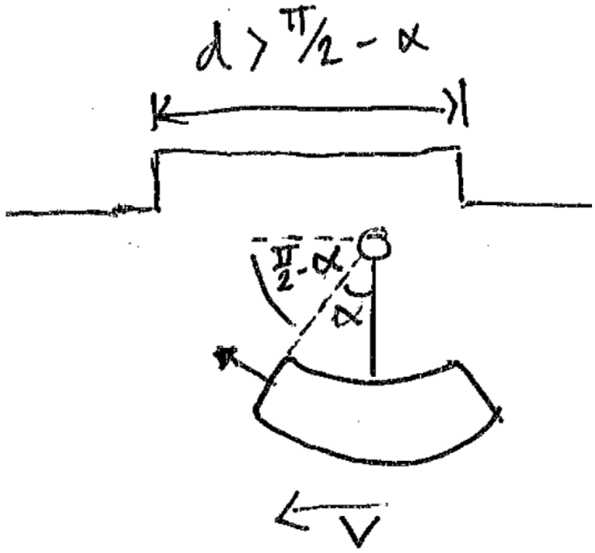


Figure 26, a weight with a latch on one end, rotating around an axis.

If the weight must rotate on an axis, the following equation describes the time it takes for the latch to apply:

$$r\left(\frac{\pi}{2}-\alpha\right)/v = t$$

Where r is the radius from the center of the pole to the center of the weight, α is half the radius of the weight and v is the initial speed of the truck (on crash/brake).

The time it takes for an object traveling in the microwave oven to reach the oven door (the object being the distance s from the door, and assuming no friction or deceleration) is described by:

$$\frac{s}{v} = t$$

Where v is the initial speed of the truck on crash/impact.

This means that for the object to impact the door before the latch is applied, the distance s must be smaller than $r\left(\frac{\pi}{2}-\alpha\right)$.

Another way to look at it is that if the latching possible over a distance larger than $r\left(\frac{\pi}{2}-\alpha\right)$, like in Figure 26, any chance of the door opening before the latch is applied is eliminated.

Consider an example of a heavy truck traveling at 50 km/h, in which a lunchbox is contained inside a microwave oven, 5 cm from its door. The width of the receiver is 3 cm. The weight rotates around an axis at a distance of 1 cm inside the panel. In this case, the locking is applied when the latch is inside the receiver (this example does not consider how the fastening is done). The information is illustrated in Figure 27:

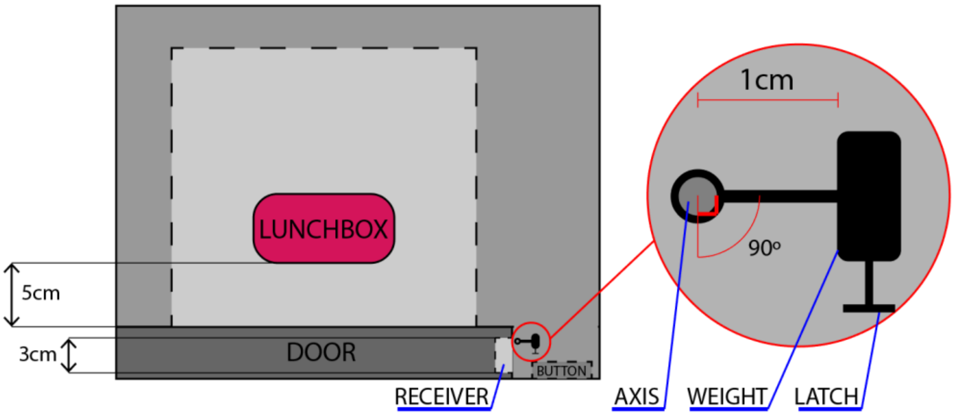


Figure 27, example of concept 1. Perspective from above.

On a crash, the weight must travel 90°, or $\pi/2$, around its axis to apply the lock. Being at a distance of 1 cm from the axis, this translates to a total traveling distance of:

$$r\left(\frac{\pi}{2}-\alpha\right) = 1 \times \left(\frac{\pi}{2}-0\right) \cong 1{,}6\ cm$$

Conversion of km/h to cm/s:

$$50\frac{km}{h} \cong 13{,}9\frac{m}{s} = 1390\frac{cm}{s}$$

The time it takes for the latch to apply is:

$$t = \frac{r\left(\frac{\pi}{2}-\alpha\right)}{v} = \frac{1{,}6}{1390} = 0{,}001151 \dots s \cong 1{,}15ms$$

Simultaneously, the time it takes for the lunch box to connect with the oven door is:

$$\frac{5}{1390} = 0{,}003597 \dots s \cong 3{,}60ms$$

In this case, the lunchbox would not reach the door before the lock is applied. But even if we assume that the lunch box lies in connection to the door before a crash, according to Figure 28, and that the door offers no resistance, the latch would apply before the door opens.

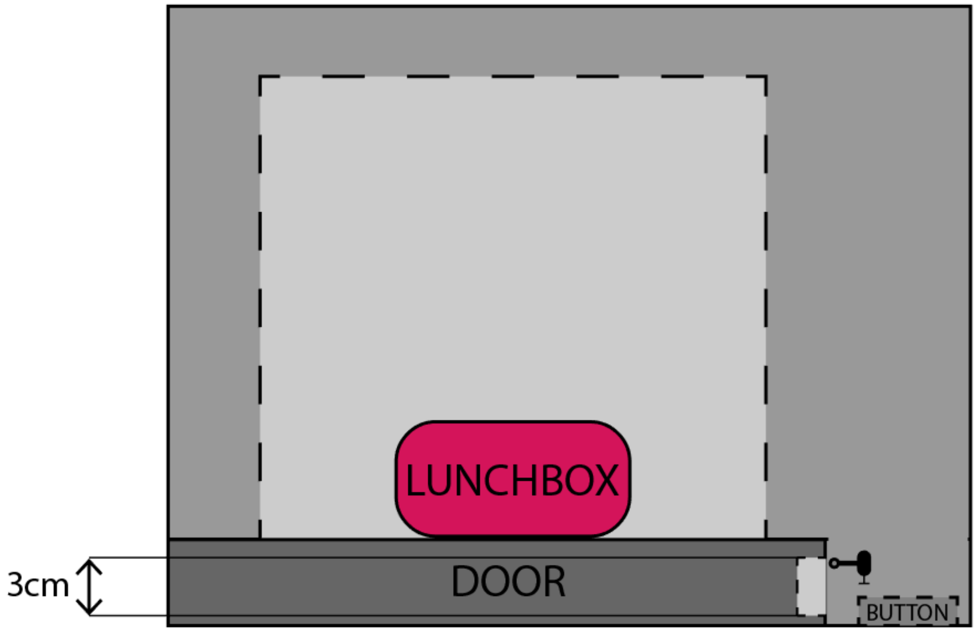


Figure 28, the lunchbox lies in contact with the door.

Because there is 3 cm over which the latch can apply, this means that the door, together with the lunchbox, must move 3 cm within 1,15 ms for the latch to fail to apply. This obviously won't happen because the weight and latch must travel a shorter distance, at the same speed, to apply. This holds true regardless of velocity so long as the distance traveled by the weight and latch is shorter than the receiver's width. This indicates that the idea is a viable option for a solution.

Four potential implementations of momentum-based ideas are presented in Figure 29.

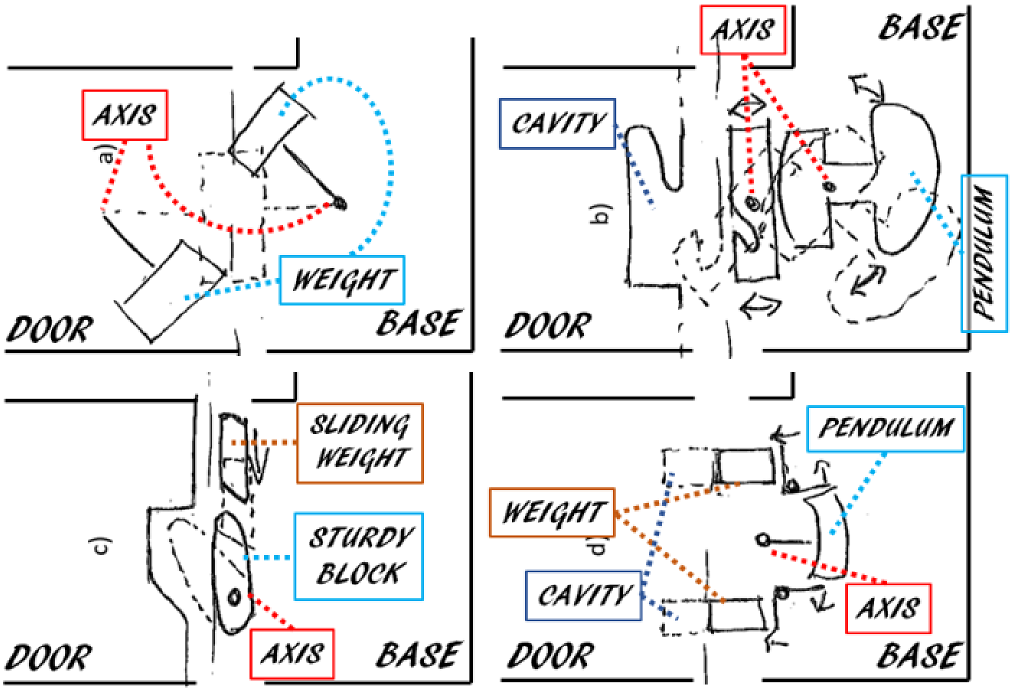


Figure 29, four theoretical implementations of a momentum-based solution, perspective from above.

Having a weight move in this manner will require something to put it back into its original position. Examples of options are springs (rotation spring or regular) and tilted movement (the weight moves slightly upwards when it engages, making it fall back into its original place by itself when there isn't a force applied to it, after the crash/brake).

Pros:

- No impact on usability.
- Potentially cheap to manufacture.

Cons:

- Durability may require more expensive materials (for example corrosion resistive materials, or treatment against corrosion).
- Requires altering of other parts either in production or afterward (for fitting the solution in the door and the base).
- One thing that must be taken into consideration is food spill, or liquid spill that adds friction or prevents the solution from functioning properly.

5.2.2 Concept 2 – The Bolt

The external solution ideas (category 2) were focused on the outside of the microwave, from the open-button to the door (Figure 30). Since the solution must be errorproof, all ideas of manual activation of a solution were discarded, if not combined with other ideas.

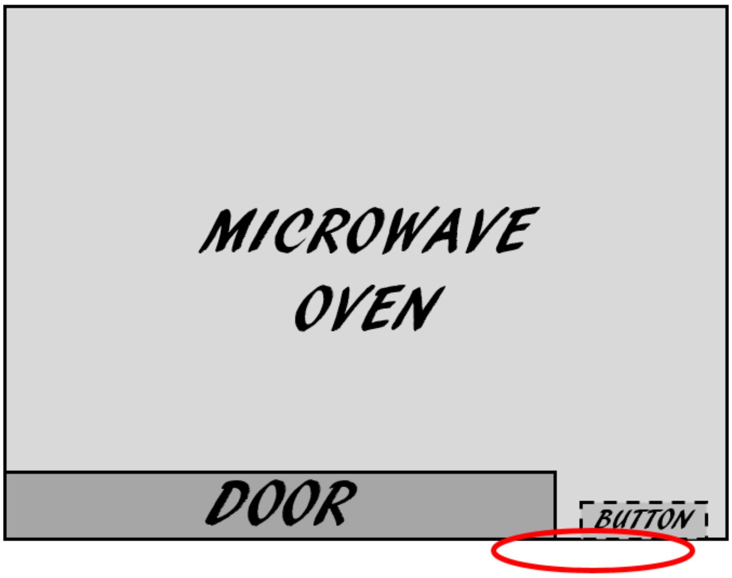


Figure 30, area of concept 2.

The external solution category consists of ideas locking the door on the outside to prevent anything falling out.

Persisting external solution ideas included blocking the door unless the button is engaged (which would open the door).

An example of how this could be done by integrating a slide bolt with the button is presented in figures Figure 31, and Figure 32. A bolt is blocking the door unless the button is engaged.

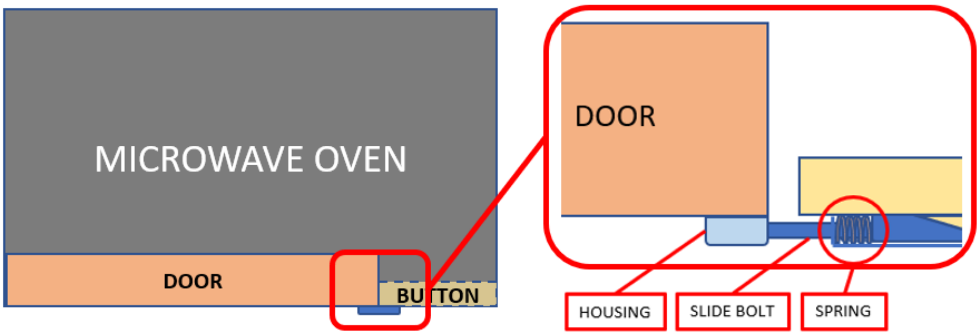


Figure 31, a slide bolt applied to a microwave button and door. Perspective from above the microwave oven.

Figure 32, the bolt is detached from the housing when the button is engaged.

The way these ideas are set up, there is no modification to the microwave oven beside applying this solution.

Pros:

- Minor modification to the microwave oven (for example one could apply adhesive to fasten the locking solution, but strength must be measured and compared with forces that are results of a crash/heavy brake).

Cons:

- The solution must be modified to fit each type of microwave oven, since the buttons may look different by design and the distance to the door from the button is not the same for all microwave ovens.
- Risk of pinching.

Other:

- In chapter 4, the moving parts were noted to possibly increase the overall required actuation force for the button. However, it is also important to note that adding a lever will reduce the force otherwise needed to push the button, but the force is instead applied to the lever. Calculations would have to be made considering the length of an added lever and the friction between the moving parts (if a lever was to be applied).

5.2.3 Concept 3 – The Modifier

Concept 3 is based on the idea of modifying parts inside the microwave oven to make the door unable to open unless the open-button is engaged. After exploring how to implement this concept, it was determined that the concept would not be universally applicable, because different microwave oven models may look dissimilar in construction. Therefore, a solution which involves redesign of details inside one microwave oven may not be applicable in another (requirement 7).

5.2.4 Comparison of concepts

Concept 1 is the baseline concept in Table 3. Concept 2 is graded with a 1 (better performance), 0 (equal performance), or -1 (worse performance), depending on how it performs compared with concept 1, according to the criteria. The Pugh's Matrix (Pugh, 1990):

Table 7, Pugh's Matrix used to compare two concepts against five criteria.

		Concept		
		The Weight	*The Bolt*	*The Modifier*
Criteria	Ease of implementation	0	1	Discarded
	Cost of implementation	0	1	
	Usability impact	0	-1	
	Development cost (complexity)	0	1	
	Reliability	0	1	
	Sum 1	0	4	
	Sum 0	5	0	
	Sum -1	0	1	
	Net worth	0	3	

The net worth indicates that The Bolt performs better than The Weight when judged by the given criteria. Client decision, aided by the Pugh's Matrix, was to go forward with The Bolt and discard The Weight.

When the concept design phase was initiated, it became apparent that translating force perpendicularly by integration with the open-button, like in The Bolt, is unreliable. Friction between parts and the spring force in the button are uncontrollable by the concept. Since integration with the button introduced uncontrollable variables, the decision was to introduce two simpler, but more reliable, solutions. Two additional concepts were introduced, referred to as concepts 4- (**The Double**) and 5 (**The Solenoid**). They were designed to behave similarly to concept 2, but with more reliable solution mechanisms (if less in accordance with the requirements).

5.2.5 Concept 4 – The Double

The Double is a bolt latch (similar to The Bolt) which is permanently applied by a spring. It requires two hands to operate, because the bolt must be manually pulled to the side as the door opens, and once released it will move back into its blocking position.

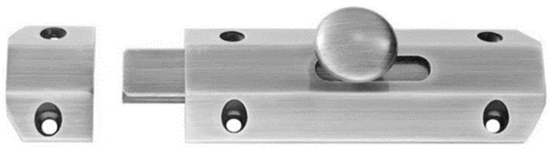


Figure 33, a slide bolt latch.

Pros:

- Simple and reliable. Has no uncontrollable elements (for example, it does not rely on the return force of the door-button)
- Does not in any way impact the microwave oven's otherwise functionality
- Minor modification to the microwave oven (adding adhesive to fasten the locking solution)
- No risk of pinching, since both hands are used to operate the microwave

oven and the locking solution

Cons:

- Requires two actions to open the microwave oven (disable the bolt latch and push the open-button simultaneously), which means it compromises on requirement 1

5.2.6 Concept 5 – The Solenoid

The Solenoid is a solenoid locking solution. It is applied when supplied electricity (for instance when the car starts, or permanently by being fed electricity from the vehicle's battery) and disabled when the button is pushed, or when the vehicle is shut off.

Figure 34, an example of a solenoid lock.

Pros:

- Automatic locking solution which requires no interaction by the user.

Cons:

- Is not a mechanical solution which means it compromises on requirement 3
- Depending on its design, access to the vehicle's CAN-bus may be desired, which compromises on requirement 8

5.3 CONCEPT DESIGN

In this chapter, the concepts are further developed and designed by 3D-modelling. The chapter concludes with evaluation of each concept with regards to the requirements introduced in chapter 1.

Since all remaining concepts are based on a bolt with some cross-section area, calculations based on crash and design materials were conducted to prove that a bolt is reliable. Because of the brittle properties, and the comparatively low breaking limit of polymers (as displayed by the tops of the curves in Figure 17, chapter 3), steel was chosen for construction material. The results of the calculations are presented in table Table 8.

Table 8, induced shear tension and shear breaking limits for two steel types.

Acceleration (m/s^2)	Lunchbox Weight (kg)	Resulting force (N)	Shear tension (MPa) on cross-section area of (cm^2):		Shear breaking limit (MPa) for steel type	
			$1\ cm^2$	$2\ cm^2$	141650	2344-02
289	1	289	0,0289	0,0145	645	367,5
	2	578	0,0578	0,0289		

According to the calculations in Table 8, the shear breaking limit has a margin by several thousand times the induced shear stress, which indicates that there is no risk of the steel breaking in the event of a crash with an item inside the oven.

5.3.1 Concept 1 – The Weight

The Weight was discarded by client decision, aided by evaluation using Pugh's Matrix.

5.3.2 Concept 2 – The Bolt

A suggestion for how The Bolt could look is presented in Figure 35. The housing is transparent for visibility.

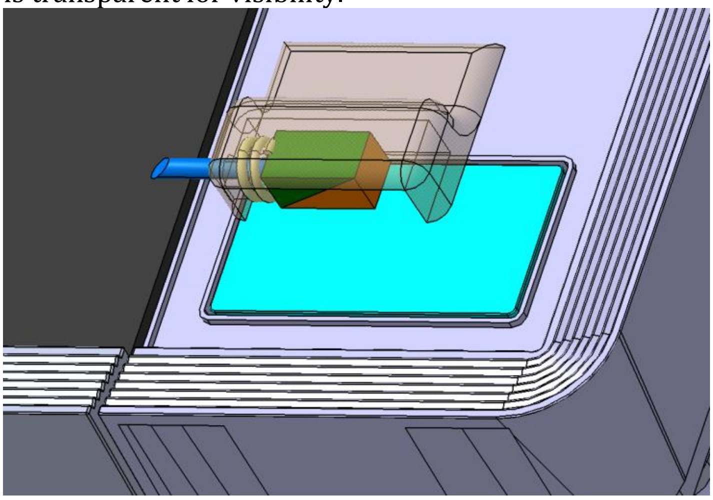


Figure 35, a CATIA-model of a suggestion for Concept 2 (applied to a microwave oven).

The concept's solution mechanism was designed to interact with the button that opens the door. Considering requirement 1, the application of the concept must be as unintrusive as possible, to allow using the microwave as it is already being used. So, the solution should be applied, for instance, onto the very edge of the button (for the button not having to be redesigned). It operates by two planes in contact at a sloped angle from the button. The top plane has a force applied horizontally by a spring. The bottom half is attached to the button. In its default position, the orange body acts as a stoppage for the green. When the button is engaged, the bottom plane follows and no longer counteracts the spring force applied to the green body, and the connected bolt slides back from blocking the door.

5.3.3 Concept 4 – The Double

Concept 4 is a simple bolt latch which is applied to the microwave oven. It is enabled by a spring, and cannot be permanently disabled. In contrast to concept 2, which interacted with the button, the lock is operated by a sliding button. If the button which pulls the bolt back is released it will again block the door – so a driver cannot disable the bolt and fail to apply it again. An example of how the concept could look is presented in Figure 36. The housing is transparent for visibility. The concept compromises on requirement 1, but its solution is more reliable than that of concept 2.

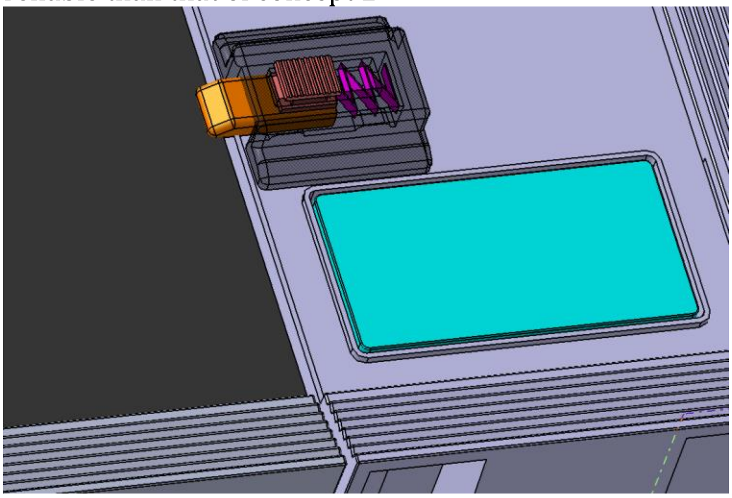


Figure 36, a bolt which is enabled by a flat spring, according to concept 4.

5.3.4 Concept 5 – The Solenoid

An idea that involves electromagnetism was introduced in the ideation phase (Appendix 4). Concept 5 is a solenoid (electromagnet with a sliding bolt) that is connected with the vehicle's CAN-bus, which allows it to activate when the truck starts. Although this idea compromises on requirements 3- and 8, it also excels with regards to requirement 1 (in contrast to concepts 2- and 4). It also introduces an additional safety element – the microwave oven cannot be opened during transport, eliminating a potential distraction for a driver who wishes to use it while driving. A solenoid lock is presented in Figure 37.

Figure 37, an example of a solenoid lock.

5.3.5 Evaluation of the concepts

Table 9 provides all requirements and each concept's solution to them.

Table 9, each requirement and the solutions by concept.

Requirements		Solution by Concept		
#	Details	2 – The Bolt	4 – The Double	5 – The Solenoid
1	None or minor impact on how the microwave oven is being used today	Concept integrated with button, as unintrusive as integrity allows	The concept compromises on requirement 1	Concept integrated with CAN-bus. Applies automatically.
2	No protruding parts or protruding parts designed in compliance with AIS 047, FMVSS 201 and ECE 21	Design in accordance with AIS 047, FMVSS 201 and ECE 21	Design in accordance with AIS 047, FMVSS 201 and ECE 21	Design in accordance with AIS 047, FMVSS 201 and ECE 21
3	A mechanical solution	Solved in ideation phase sifting	Is a mechanical solution	Compromises on R3
4	No detaching parts on brake or crash	No obviously weak parts *Requires future validation of an applied prototype*	No obviously weak parts *Requires future validation of an applied prototype*	No obviously weak parts *Requires future validation of an applied prototype*
5	The solution must bear everyday use of the integrated oven without impacting its (the solution concept's) function on a crash/brake	*Requires future validation of an applied prototype*	*Requires future validation of an applied prototype*	*Requires future validation of an applied prototype*
6	No hindering the installing of the integrated microwave oven	Concept is exclusively located on the exposed front acc. limitation 1	Concept is exclusively located on the exposed front acc. limitation 1	Concept is exclusively located on the exposed front acc. limitation 1
7	Applicable on most button-to-open microwaves	Fulfilled by design	Fulfilled by design	Fulfilled by design
8	Applicable regardless of the microwave oven's location inside the cabin	Assuming exposed front acc. limitation 1, this requirement is fulfilled by design	Assuming exposed front acc. limitation 1, this requirement is fulfilled by design	Compromises on R8, requires connection to the CAN-bus

In summary:

- The Weight and The Modifier are discarded.
- The Bolt fulfills requirements but depends on uncontrolled variables (which makes the solution unreliable)
- The Double compromises on requirement 1 but provides a reliable solution
- The Solenoid compromises on requirements 3- and 8, but excels with

regards to concept 1, in contrast to The Double.

5.3.6 Answers to guiding questions 2- and 3

Table 10 provides answers to guiding questions 2- and 3 by each solution concept.

Table 10, each concept's answer to guiding questions 2- and 3.

	Q2 – Preventing projectiles	Q3 – Affect on usability
2 – The Bolt	By locking the microwave oven door with a bolt latch	Minor impact on usability, but unreliable by design
4 – The Double		Compromises on R1, but reliable by design
5 – The Solenoid		No impact on usability, but compromises on R3 and R8 as a result

5.4 FINAL RESULT

The Double is judged as the best solution, by its simplicity and reliability.

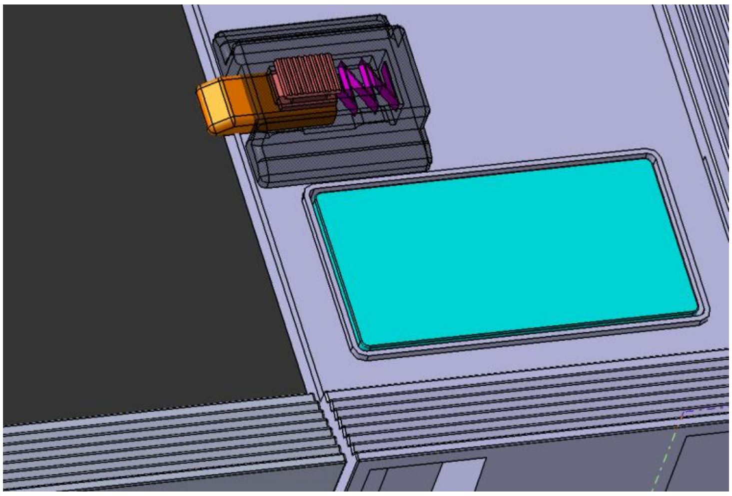


Figure 38, The Double. A bolt which is enabled by a flat spring.

6 Discussion

This chapter is divided into subchapters which discuss the criteria used for the first concept evaluation, the position of the result with regards to the requirements, and the relevance of this thesis from a future development-, societal-, and truck driver point of view. It also provides reflection and conclusions drawn based on how the result relates to the guiding questions. The chapter concludes with recommendations for a truck driver seeking a solution to the issue which incentivized the thesis work, and for anyone seeking to develop a solution to a similar problem with the same or other requirements. It also provides recommendations for future work.

6.1 PUGH'S MATRIX CRITERIA AND EVALUATION OF THE BOLT AND THE WEIGHT

This sub-chapter discusses how The Weight and The Bolt perform according to Pugh's Matrix criteria.

6.1.1 Ease of implementation

The Weight would require fitting the solution inside the panel of the microwave oven, and making a cavity in the door where the locking bolt is applied. The Bolt requires you to attach it to the button area, for instance with screws. It follows that The Bolt performs better when matched against this criterion. For these same reasons, it also performs better for cost of implementation.

6.1.2 Usability impact

The Weight is effectively invisible to the user, so the usability impact for this concept is null. For The Bolt, the solution certainly affects usability. Without having asked interview questions about preferability of a lever (whether sliding or lifting) or a turning button over a regular button, one can hardly claim with any certainty that this would increase usability. For this reason, it was judged as scoring worse than the baseline The Weight. It should also be noted that the solution of The Bolt doesn't have to be a sliding or rotating solution. It could also be an extension of the current button.

6.1.3 Development cost and reliability

The reliability of a proposed concept can be analyzed in terms of development cost and complexity. The process of determining the reliability of a concept is called validation (WSP Sverige AB, 2016). If a concept is obviously complex, it follows that the development cost will be greater than that of a simple concept. The Weight requires extensive testing to make sure of its longevity, how it performs after being in corrosive environments, how it performs when very cold or warm, etc. The problem with the solution being "invisible", is that a user won't know if it is defect. To ensure its reliability, one must simulate aging through climate chamber testing and crash testing. The result of these processes is a very expensive development phase to make sure that the solution works after many years. The Bolt is a passive solution, and its reliability is not as hard to test. Also, in contrast to The Weight, The Bolt is visible on the microwave oven. In theory, the door of the microwave shouldn't be able to close if the bolt is stuck, since this would mean the button is also stuck. This makes a faulty locking solution impossible to not spot. If one makes sure the construction is sturdy, the development cost won't be nearly as high as for The Weight. It must be noted that The Bolt also has issues with regards to reliability, because the return force of the button is an uncontrollable variable, and it is yet to be proven that the friction in the moving parts can be overcome by the return force in the button (if it would be integrated with the button).

6.1.4 Other

It is important to note that this solution is a safety solution. If the goal was to improve usability of the microwave oven, one might have replaced the springs in the already existing button to make it easier to press, or decrease friction in the mechanism of opening the microwave, which would also have made opening the door require less actuation force (but would in turn make the microwave oven less safe). For this same reason concepts 4- and 5, that are introduced as an alternative to concept 2, compromises on some requirements to provide a more reliable solution.

6.2 POSITIONING THE RESULT

The idea of a locking solution according to the requirements presented in chapter 1 proved hard to develop, because the requirements later appeared to somewhat contradict each other. Requirement 1 specifies that none or minor impact on how the microwave oven is being used today is desired, and requirement 7 expresses a desire for the solution to be universally applicable. When evaluating ideas for their implementation it was quickly realized that for a solution to be universally applicable, it could not be applied inside the microwave oven because different brands make microwave ovens that look different on the inside. This forces the solution to be an external one, which puts it in the area where a user operates the microwave oven. Furthermore, because a mechanical solution was desired, the activation of the concept had to come from an external force. In this case, it would directly (for instance by disabling a bolt latch) or indirectly (by pushing the door-button) come from the user. Having the solution activated by a user, while simultaneously desiring no affect on usability, proved a hard task to accomplish. This is the reason that The Solenoid was proposed, to present a solution with some contrast to the concepts that fit better within the requirement specification. I hope that this thesis work can give information to anyone developing a similar idea in the future, and guide them in selecting their requirements by seeing what results the requirements presented here yielded.

For a simple, cheap solution which applies reliably, it turns out that a simple bolt latch might be the most appropriate product. Concept 5 serves as a recommendation for future work if the solution mustn't be mechanical or have the option of positioning anywhere in the cabin. It could potentially be an elegant, universally applicable solution according to other requirements.

6.3 RELEVANCE

The thesis work serves as a recommendation for potential future development. For the client, the thesis work is theoretical (meaning that there are no concrete plans for future development at this point). Lacking, in my opinion, a truly elegant and unique concept as a result of this thesis work, I believe that it serves as an indication for which requirements not to base a universally applicable locking solution for these types of integrated microwave ovens on.

Alternatively, from a societal point of view, a bolt latch solution designed to be fitted onto a microwave oven with a strong adhesive will increase safety in a truck cabin environment during a crash, and this thesis work shows that given these requirements (which apply to most microwave ovens and truck cabin environments), a bolt latch solution is a cheap and reasonable concept.

For a truck driver, the obvious recommended solution is to not have an item inside the microwave oven during transport. In my interviews, the drivers seldom used the microwave oven during transport. If a driver deems it necessary to use the microwave oven during transport, this thesis may serve as a recommendation to invest in a simple bolt latch if he/she has purchased a microwave oven for use in their truck cabin. It is important that they choose a properly strong adhesive (such as a strong epoxy adhesive) to fasten the solution.

6.4 REFLECTION

When studying some CAD-models of microwave ovens (which cannot be referenced due to confidentiality) it becomes apparent that the door should not be able to open when the button is not engaged. A quick analysis concludes that it likely opens due to plastic details bending elastically when enough force is applied. If a new microwave oven is developed, one should consider switching some internal parts from the usual plastic, to, for instance, metal. This should make the door opening mechanism significantly more resistant to opening from force being applied from inside the oven.

I believe it would have been interesting to collect data on actuation force and return force for microwave oven buttons. Meaning, how much force is required to open the microwave oven door by pushing the button, and how much force does the button return with? In the context of concept 2 it would have been interesting to have a general idea of how much force the button, generally, pushes out with. By simple calculations, it would have been easy to get an idea of how much force this translates to horizontally when pushing the lever into its blocking position (and if the force applied by the button returning can overcome the friction as well as the spring force).

I don't think more interviews with truck drivers would have yielded more good information. This is something I thought about during the thesis work (whether I should interview more), but I believe that I was finding a solution for a worst-case scenario (for example lets pretend one puts 3 kg worth of items in the oven) which would then cover all other scenarios as well. Therefore, it would be unnecessary to gather more data on the habits of truck drivers with regards to heating food. However, it was necessary to conduct a few initial interviews to learn potentially interesting information. Without speaking with any truck drivers, one would not know if something might have been missed.

It is also worth noting that changing the requirements and the scope in general for the thesis work would likely have yielded quite different results. Perhaps concept 5 would have been one of the concepts developed in the concept development phase. The idea of connecting an electrically activated solution to the CAN-bus system of the vehicle is interesting, and is a more unique and potentially elegant solution than what was eventually presented (except for this concept). Also, it would not have compromised on the affect on usability, the theory of which was introduced in chapter 3.

For me, the most important part was errorproof design of a solution that has potential to work in real life. This is something achieved by the simple bolt latch solution which is enabled by a spring. It is unfortunate that it compromises on usability, but the incentive for the thesis work is safety – so the utility could not be compromised on.

During the thesis work it would have been convenient to have complementary information available, such as the actuation force required for buttons, as well as the return force of the buttons provided by their internal springs. When conducting calculations on the force on the inside of the microwave oven door on a crash (because of an item crashing against it) no consideration was taken to how much energy is absorbed by the door before it engages the locking solution outside it. For future work it is recommended to measure the force required to open the door without pressing its button, as well as actuation and return force of the button (in different ovens).

Finding proper adhesives will be required if any concept is to be developed further. In the same context, the materials must be considered. Both with regards to friction (for instance in the planes of concept 2) and the adhesive strength between the material in the concept and the plastic material of the microwave oven panel/door.

6.5 CONCLUSIONS

The **aim** of the thesis work is to improve truck cabin safety by decreasing risk of flying parts from a microwave oven during a crash/heavy brake - without impacting microwave oven usability.

The **goal** of the project is to develop a concept for preventing items from falling out of a microwave oven during a truck crash/brake.

This thesis does not account for fastening a microwave oven, nor improving on its overall design. It does suggest three concepts for future development consideration for securing the door of an already in place microwave oven in a truck cabin environment. As was previously discussed in this chapter, *not impacting microwave oven usability* has been compromised in concepts 2- and 4.

The concepts presented in the concept design phase of this thesis work prevent items from falling out of a microwave oven during a crash/brake by fastening the door with a locking solution.

To achieve the goal of the thesis work, the following **guiding questions** are evaluated:

Q1. How and when are microwave ovens in truck cabins used?
Q2. How can items in a truck cabin microwave oven be prevented from falling out during a crash/hard brake?
Q3. How will a proposed solution affect usability of the microwave oven?

6.5.1 Q1 - How and when are microwave ovens in truck cabins used?

Information is provided on what items can be expected to be in the microwave oven, and concludes that items may be inside the oven when the truck is moving. From a design point of view, this emphasizes the need for an errorproof design, so items cannot fall out of the oven at any time. It also serves as an indication for strength required and by extension a recommendation for cross-section area for the bolts suggested in the final concepts. This data is provided in chapter 5.3, page 39.

It has also been concluded that food may, and most importantly can, be cooked/heated in the microwave oven during transport. This confirms the necessity of a solution for preventing flying parts from within an integrated microwave oven during a truck crash. The solution does not have to be universally applicable, but if none exist, an integrated microwave oven for truck cabins that is not protected by a shutter or jalousie, or contained in a box, should have an individually fitted solution (or be constructed accordingly).

In chapter 2, a custom microwave oven has been integrated by a truck driver. The fact that drivers sometimes integrate microwave ovens on their own implies that there are few limitations to where in the truck cabin a microwave oven can be positioned. When scouting the internet for microwave oven solutions for truck cabin use, it was discovered that there are many solutions for fitting the oven, for example by adding a shelf behind the driver on head-level (Kuda UK, 2017).

6.5.2 Q2 – How can items in a truck cabin microwave oven be prevented from falling out during a crash/hard brake?

During the thesis work, by sifting of ideas according to limitations, requirements, and client, only external solution ideas remained when the concept development phase was ended. All external solution ideas focused on preventing the door from opening during a crash/brake, which is why all concepts presented in the concept design phase were based on this idea.

Had the requirements been different, for instance if the solution didn't have to be universally applicable, it is likely the final concepts would have looked more diverse, with internal modifications to a microwave oven also presented with the concepts.

6.5.3 Q3 – How will a proposed solution affect usability of the microwave oven?

As was previously discussed, both concepts The Bolt- and The Double compromises on this point. The justification is that errorproof design is more important because this thesis work focuses on safety rather than convenience. With all requirements considered the concepts proved difficult to develop without any compromise, so this was the chosen route.

For The Bolt, the affect on usability lies in the button press. A small area of the button is restricted with this solution applied, so a user may no longer push the button in the upper left corner. This is not likely to be a major issue for any user, but it may affect usability nonetheless. The solution also introduces the friction between the sloped planes of the orange and green bodies (Figure 39, left-side), which increase the actuation force for the button. The extent of this actuation force increase must be explored with applied prototypes, since even well-performed calculations are unreliable when safety solutions are concerned (Whitworth, 2012). Calculations may, of course, provide an indication, and as such have been provided in some cases in this thesis work.

3D-renderings of The Bolt and The Double are presented once more in Figure 39 for convenience.

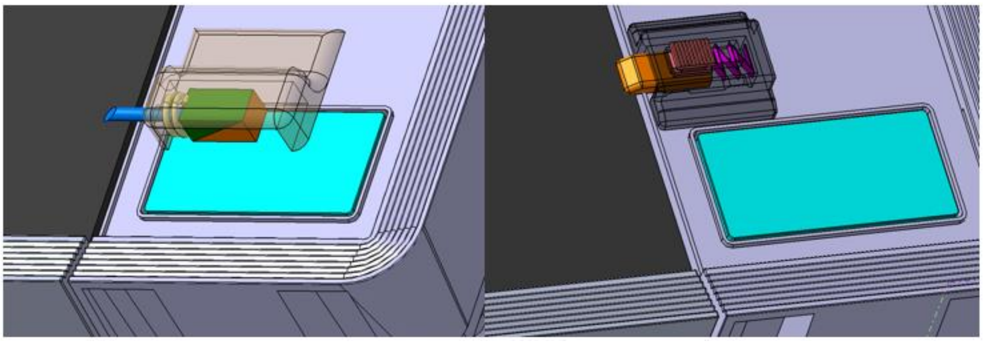


Figure 39, 3D-renderings of concepts The Bolt- and The Double.

The Double affects usability by forcing the user to slide the bolt from its locking position while simultaneously pressing the button that opens the door. This is obviously a substantial change to how the door is usually opened, as it provides an additional element for doing so.

Concepts The Bolt- and The Double are errorproof by design since they are automatically locked. The former automatically locks when the door button is released, and the latter is permanently locked unless temporarily disabled by user interaction.

The Solenoid doesn't affect usability since it is automatically applied and requires no user interaction. It can be made errorproof, if it is permanently applied by the vehicle's batteries, and only disabled when the button is pressed.

6.6 RECOMMENDATIONS

Prototype(s) will be required for future work to perform some early validation of the concept(s) to verify its/their potential.

Future work recommendations include:

- Measuring actuation forces of buttons in different ovens
- Measuring return forces of buttons
- Measuring force required to force open the door when no locking solution is applied

- Material research to determine suitable materials with low friction and strong adhesive properties
- Determine a strong and reliable adhesive

For future development, concept 2 is recommended if requirements and limitations of this thesis work must be fulfilled. If requirements can be compromised on, concept 5 is recommended for future development. Concept 4 is a simple, reliable and low-cost alternative solution.

For designing a new microwave oven, it is recommended to construct it with rigid material in moving parts or to integrate a locking solution that is designed for the specific microwave oven model internally.

In my own experience, from doing this thesis work, I think that a locking solution should be integrated internally in a microwave oven, even though it requires an individually designed concept (for the most part) for each microwave oven. I hope that the thesis work serves to guide anyone developing a concept for a locking solution to focus on their individual product, rather than try to develop a universally applicable solution.

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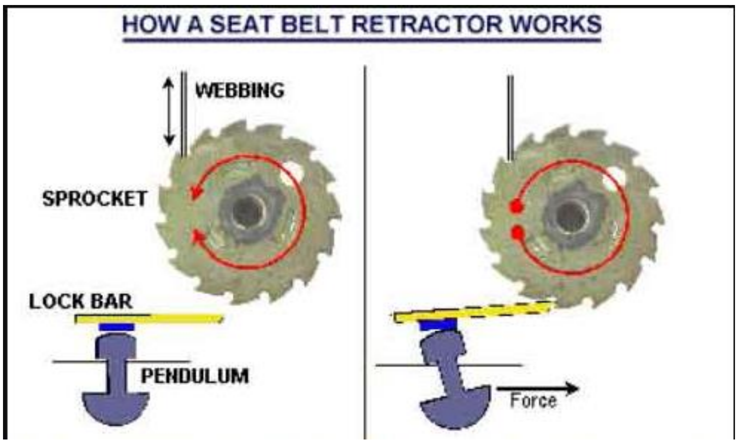
Appendix 1: Locking solutions

Examples of locking solutions are those of seatbelts, ethernet cables, and car brakes among others. The principles used in these items are also in use many elsewhere. In this subchapter will be presented information on some locking mechanisms

Seatbelts
There are different types of seatbelts. One example of a seatbelt is the three-point belt (in use in cars today). There is a passive and an active element to the modern seatbelt.

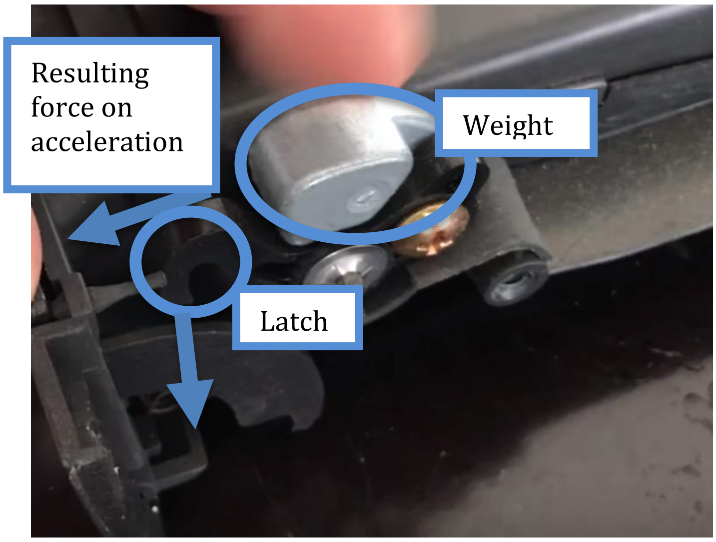
The **active element**; On a crash, what is called *pre-tensioning* will occur. This is when the seatbelt is pulled towards the passenger as a small explosive charge is activated (by electrical impulse) before the body flies towards the steering wheel. This allows the body to fall with the belt, instead of it striking against the seatbelt as it falls forward (if this happens it is more likely a crash victim will brake ribs – it is also why one is adviced not to wear the seatbelt outside a jacket but instead to have it under the jacket, close to one's body).

Passively, a seatbelt will lock on heavy brakes or when the car is leaning at an angle (like when the car is parked in a slope). An example of how this works is presented in Appendix 1, Figure 1. The pendulum will move on brake, crash or when the car is moving at an angle, effectively locking the cog wheel (by forcing a lock bar against a cog) attached to the seatbelt webbing roll which in turn prevents the seatbelt from being pulled out further.



Appendix 1, Figure 1, an example of a passive locking mechanism in seatbelts.

An example of where a similar principle is in use is in a dashboard compartment in a Honda Civic. In this case it seems intended to prevent the dashboard compartment from opening during acceleration or when driving up a slope (Appendix 1, Figure 2):



Appendix 1, Figure 2, dashboard compartment locking mechanism in Honda Civic.

Brake disks
Brake disks are in use in cars and bikes (and in other places). The mechanism is simple: it locks by two surfaces preventing or restricting movement relative to one another through friction.

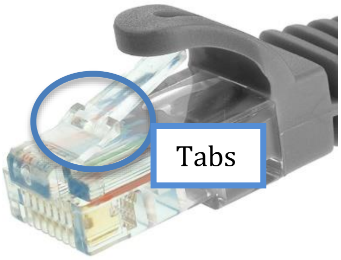
Nuts
Locking by screwing a nut onto a thread (and against a surface). The nut is kept in place by friction. A nut and a screw are presented in Appendix 1, Figure 3.


Appendix 1, Figure 3, a nut and screw.

Resistance against vacuum
The function of suction cups. Locks against a surface because of the principle of nature not wanting vacuum to exist.

Doors
How your door stays shut. Simply by the strength of the materials lying against each other in the door frame (and against the door itself in the other end).

Ethernet cable
A regular ethernet cable has one or two tabs which attach themselves to the inside of a socket. An example of how an ethernet cable look is presented in Appendix 1, Figure 4.



Appendix 1, Figure 4, an ethernet cable head.

To detach the cable, simply push on the tabs.

Excenter lock

A steel hook is threaded over a latch, fastening it manually. An example is presented in Appendix 1, Figure 5.

Appendix 1, Figure 5, excenter lock.

Appendix 2: Visits and interviews

All visits and interviews were conducted in August 2017.

For finding out about potential solutions on trains with regards to locking mechanisms and/or strengthening the door seal during a crash/brake, Bombardier and SJ were contacted:

- Bombardier
  - A manufacturer of trains and airplanes, among other things.
  - Did not provide any information. No contacts knew about any requirements put on microwave ovens or their locking mechanisms. After being advised to contact many different people, focus was put elsewhere.
- SJ
  - A commercial train travel company in Sweden
  - Did not provide any information about safety regarding microwave ovens or kitchen machinery on their trains. The story is like that of Bombardier. A picture of a microwave oven in an SJ train is presented in chapter two.

For finding out about potential solutions on boats with regards to locking mechanisms and/or strengthening the door seal during a crash/brake, Stena Line was contacted. No information was uncovered, but I was advised to contact Loiparts, a company that focuses on marine galley solutions for kitchen machinery and other things.

A visit to Autoliv was conducted to learn about the locking mechanisms involved in seat belts. Autoliv is a world leading car- and truck safety company. Information about the elements of a common seat belt is presented in appendix 1.

A Volvo trucks sales location was visited to look at a truck cabin environment in which an integrated microwave oven could be found.

Truck transportation companies including DHL, GLC, and Schenker were also visited spontaneously:

- DHL
  - I wasn't allowed to come inside and speak with any truck drivers, nor was I provided the contact information to an overseer for the drivers when I requested it.
- GLC
  - GLC drives trucks locally, and the trucks did not have any microwave ovens installed.

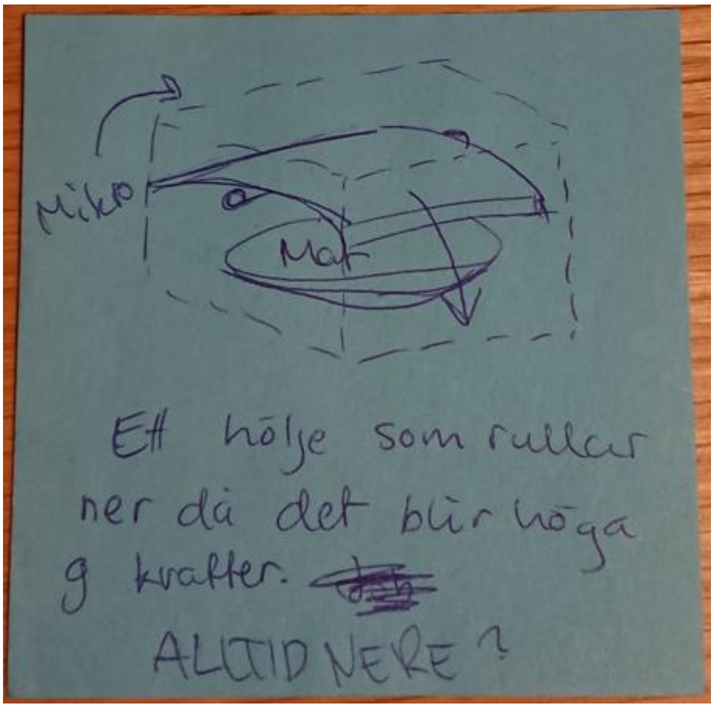
- Schenker
    - I wasn't allowed to speak with any drivers nor provided the contact information to an overseer for the drivers

Two truck parkings outside Gothenburg was visited. Four truck drivers were interviewed.

Appendix 3: A few interesting/unique ideas

A sample of creative ideas from the ideation workshop are presented in appendix 4 figures: Appendix 4, Figure 1, Appendix 4, Figure 2, Appendix 4, Figure 3, and Appendix 4, Figure 4.

Appendix 4, Figure 1 depicts a jalousie inside the microwave oven. On crash, the jalousie moves into forward position, blocking whatever is inside the microwave oven from falling out.

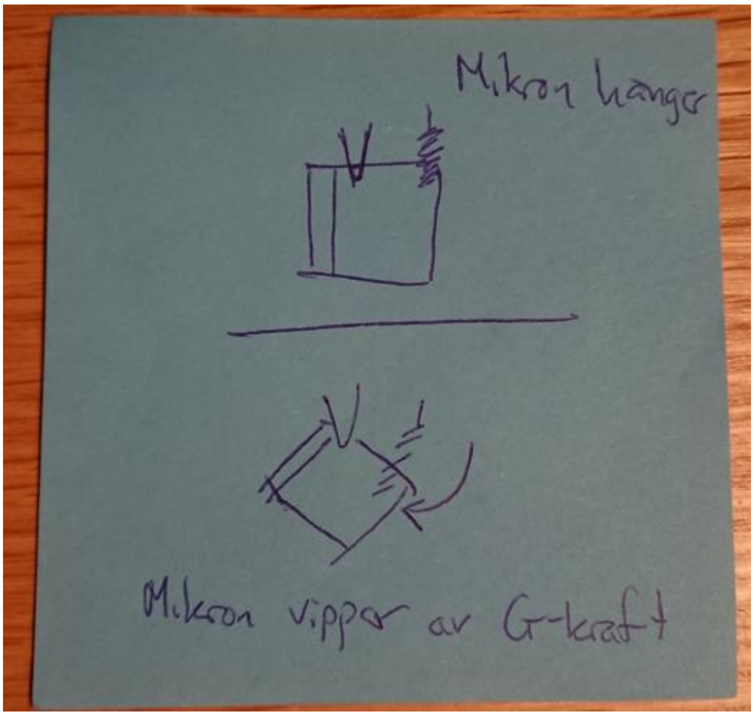


Appendix 4, Figure 1, an idea-note of a jalousie inside a microwave oven.

Appendix 4, Figure 2 illustrates a microwave oven that is locked by an electromagnet. An electromagnet is engaged (effectively locking the door) when the truck is running, which is disabled when the microwave door open-button is pressed. Could be powered by the current power supply.

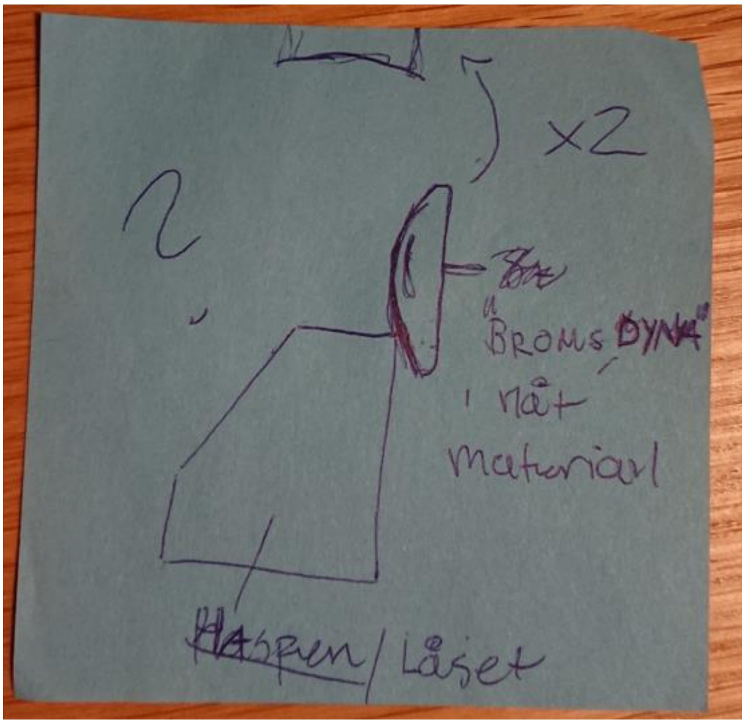
Appendix 4, Figure 2, a microwave oven locked by an electromagnet.

In Appendix 4, Figure 3, the microwave oven tilts on crash or heavy brake, altering the movement of internal objects reducing horizontal momentum greatly (and in turn reducing perpendicular force exerted on the microwave oven door).



Appendix 4, Figure 3, a tilting microwave oven.

In Appendix 4, Figure 4, a friction pad is added to the parts currently keeping the microwave oven door closed.



Appendix 4, Figure 4, a friction pad inside the mechanism of a microwave oven.